NASA Micro-g NExT Challenge: Sample Container Dispensing Device

Final Design Review Report

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ABSTRACT

This Final Design Review (FDR) report outlines a Cal Poly San Luis Obispo senior design project developing a sample container dispensing device for NASA Johnson Space Center's Micro-g NExT design challenge, a competition for university students. NASA aims to bring the first woman and next man to the moon through the Artemis missions beginning in 2024. The Micro-g NExT 2021 challenges focus on developing equipment which will support the Artemis mission, where Astronauts will conduct extensive geological sampling to further the scientific understanding of the moon. Our team designed, built, and tested a device that holds sample bags as they are being filled during lunar surface extravehicular activity (EVA) operations. Through participation in the design challenge, the resulting sample container dispensing device will be tested in NASA's Neutral Buoyancy Lab, with the potential to become the baseline design for the actual mission hardware. This document begins with our Background research conducted thus far to establish the problem definition. The Objectives section discusses the scope of the project, followed by the Conceptual Design section which details the process utilized to determine the design direction. This progresses to the Final Design chapter, describing the prototype as built. Implementation and testing of the design is discussed in the Manufacturing Plan and Design Verification sections. Lastly, the Project Management section provides an overview of the project development as well as resources utilized throughout. This report is supplemented by appendices including additional visuals, matrices, analyses, and more.

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1 INTRODUCTION

Our team, the "Mustangs on the Moon", is comprised of three mechanical engineering seniors at California Polytechnic State University, San Luis Obispo. We are participating in the 2021 NASA Micro-g Neutral Buoyancy Experiment Design Team (Micro-g NExT) challenge for our senior design project. The Micro-g NExT challenge is an annual event through Johnson Space Center which provides an opportunity for undergraduate students to execute the engineering design, build and test processes to address a current space exploration challenge. This year, challenges focus on the upcoming Artemis missions to return astronauts to the moon.

Our team developed a solution to support lunar surface extravehicular activity (EVA) operations by creating a device to dispense sample bags which will hold geological samples. Micro-g NExT provided challenge descriptions which include a series of engineering requirements, including a focus on ease-of-use for the astronauts, who must be able to operate the sample container dispensing device with only one spacesuit-gloved hand. Our final hardware will be tested underwater in the Neutral Buoyancy Lab (NBL) to simulate low-gravity conditions. If our device proves successful, it could be used as a basis for future designs of the hardware which will travel to space.

This document outlines the design process, chosen design direction, and the creation of a verification prototype (VP). First, we summarize a portion of the background research conducted to gain a complete understanding of the challenge presented. We synthesized our findings from the background research to determine the objectives of our project in terms of our goals and deliverables. From the objectives, we determined the design direction through a conceptual design process. After initial evaluation of the concept design, we established the final design direction. We implemented a thorough manufacturing plan and verification plan to build and test the design. Next, we include a description of the project management methods used to track tasks, resources, and milestones. Lastly, we provide our conclusions and recommendations after completion of the project.

2 BACKGROUND

In this section, we present our findings from our background research. Our research included a variety of methods, such as sponsor information sessions, analysis of previous lunar missions, investigation of similar technology, and more. This information provided a basis of understanding to develop solutions during ideation.

2.1 Context of Micro-g NExT Competition

Considering our project is a design challenge, we first sought to gain insight into the context of the competition. We found information regarding the facilities where testing will occur, the objectives of the Artemis mission which our design aims to support, and more. These findings are summarized below.

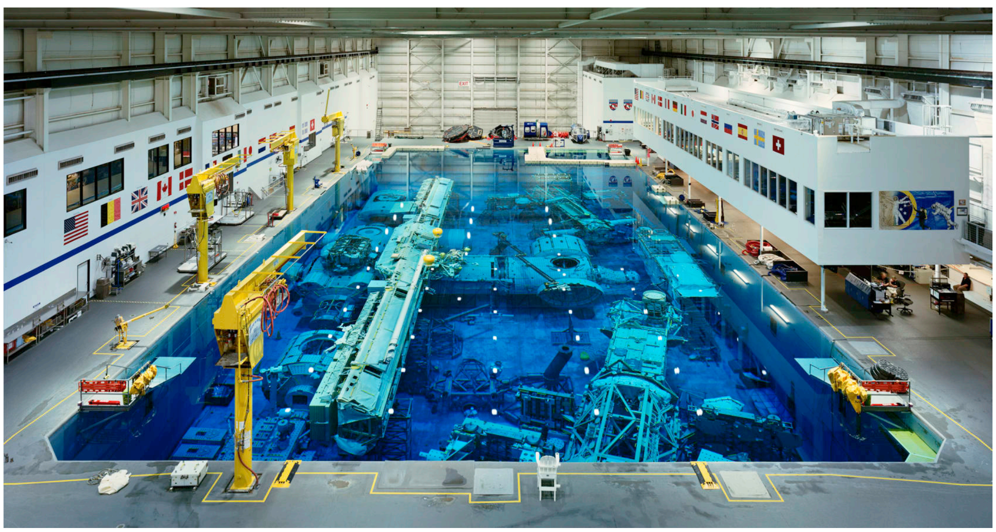


Figure 1. Photo of the NASA Natural Buoyancy Lab [1].

We first examined a document that provides information regarding NASA's Neutral Buoyancy Laboratory, located near the Johnson Space Center in Houston, Texas [1]. This information is crucial because if our design is accepted by the Micro-G NExT committee, we will send our device to the Neutral Buoyancy Laboratory in Texas to have testing procedures conducted on our Sample Container Dispenser.

We also sought further information on the Artemis missions for which our device is intended, and we found the complete, official NASA Artemis mission description [2]. Their goal is to reach the moon by 2024 to continue the lunar exploration which started in July of 1969. This helped us to fully understand what our design is going to be used for. In this report, we also found a list of equipment the crew will have at their disposal once they land on the moon. Furthermore, they provided more insight into their planned lunar operations. This section directly relates to us as it explains what they plan on sampling, how much they intend to bring back, and for what they plan on using it. This information is crucial to our design as the astronauts would theoretically be using our device to dispense the sample bags and collect the rocks and particles.

2.2 Summary of Sponsor Information Session

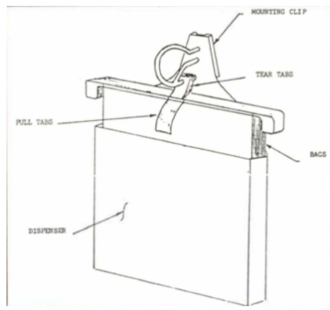
Because our project is an entry in a design competition, we initially did not have a direct user with whom we could interact. However, we were able to attend an information session for the Micro-g NExT program via teleconference [3]. This was a one-hour presentation with the program coordinator, activity manager, and several subject matter experts whose work related to the challenges. Some of the important information we learned is bulletized below:

- What is Micro-g NExT?
    - Addressing NASA challenge in immersive experience including developing technical documents and writing proposals, building out device, and testing in NBL how EVA tools are normally tested
    - Selected teams will get NASA mentor and subject matter expert
    - Competitive process, proposals will be evaluated by scientists and engineers at NASA centers
    - Student contributions have been recently used for astronaut training and inspired real devices used on spacewalks on the ISS
- Overview of Timeline
    - Phase 1: Current phase, conducting info sessions, developing proposal
    - Upcoming deadlines: letter of intent, concept proposal
    - Nov 2- Dec 3 is proposal evaluation period
    - Phase 2: Dec 9 - team announcement
    - December: mission briefings, participant orientation, online activities and focus sessions
    - June 7-12 prototype testing event #1, June 14-19 prototype testing event #2
- Challenge #3 Overview - Lunar Surface EVA Operations - Sample Container Dispensing Device
    - Presented by Mary Walker - project manager in EVA tools and equipment group
    - Sample bags are similar to those used in Apollo missions
    - Metal rim on bags that can deform and open, close it and roll it up
    - Dispenser must hold 20 bags, single handedly open bag, remain on dispenser open to fill if needed

2.3 Existing Designs

The Micro-g NExT challenge description stated the sample bag design they are planning to use for Artemis is very similar to that of the Apollo missions. With this in mind, we largely focused on looking at the context of the Apollo missions, though we also looked to some consumer applications that require a bag to be held and filled simultaneously. Some of these products are shown in Table 1.

Table 1. Existing designs relevant to the lunar surface sample bag dispenser.

Product Name	Image	Description
CUP-SHAPED DOCUMENTED SAMPLE BAG [4]		This cup shape sample bag dispenser was one variation sent on the Apollo missions. This allowed for the bags to be held securely and stay open while being filled.
DOCUMENTED SAMPLE BAG DISPENSER [4]		This is the bag dispenser used in the Apollo missions, holding the bags via plastic tab which was broken when the bag was used, and the bags were enveloped in a Teflon cover. This did not allow for the bags to be held open on the dispenser while being filled.
COMMERCIAL PLASTIC BAG DISPENSER [5]		This is a plastic bag dispenser as often seen in commercial applications such as in grocery stores. It allows bags to be held open while they're being filled
INDUSTRIAL BAG FILLING MACHINE [6]		This product shows two horizontal rods used to hold the bag up while a base supports the bottom as the bag is filled, which could be a useful characteristic for our bag dispenser as geological samples are collected.
COFFEE BAG FILLER [7]		The coffee bag filler shown is another commercial application, with similarity between coffee bags and the sample bag rims. Once again, this shows that supporting the bottom of the bag is essential.

2.4 Patent Search Results

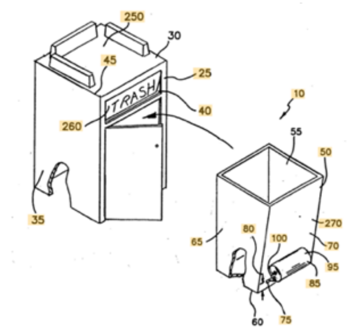


Figure 2. Trash Receptacle with Attached Bag Roll and Dispenser.

The first patent that matches closely with the design requirements of the Sample Containing Dispenser is the Trash Receptacle with Attached Bag Roll and Dispenser. This product is a trash can that has an attachment in the back that holds rolled up trash bags. The trash bags can easily be changed as the user pulls one bag out, the next bag is pulled into place.

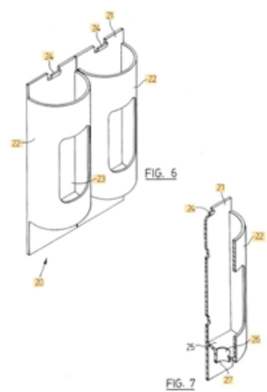


Figure 3. Flexible Container Having a Retractable Dispenser.

The next product is called the Flexible Container Having a Retractable Dispenser. This design provides a new look at containing the bags. It provides a unique opening that would allow for a method of dispensing the bags.

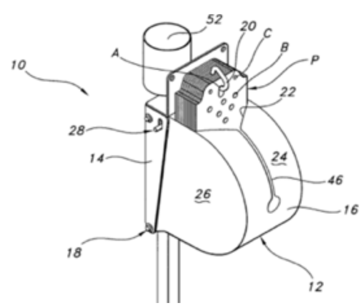


Figure 4. Dispensing Apparatus for Plastic Bags.

The third patent found is called Dispensing Apparatus for Plastic Bags. This product utilizes tear away bags on a metal hook, similar to the original Apollo design. The end if the bags are stored in a rounded closed compartment.

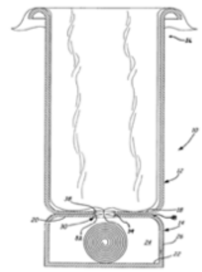


Figure 5. Receptacle with Dispenser.

The fourth design is the Receptacle with Dispenser. This product is similar to the first patent, where it has an isolated compartment designated to store rolled up trash bags. When a bag is lifted from the receptacle, another bag is pulled into the ready position.

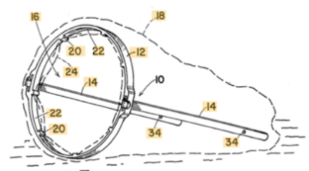


Figure 6. Bag Opener.

The fifth design is titled the Bag Opener. The design features two prongs that are inserted into a bag so the mechanism can easily align to the bag. Then, the circular feature clamps to the opening of the bag to ensure the bag stays open and is easy to fill.

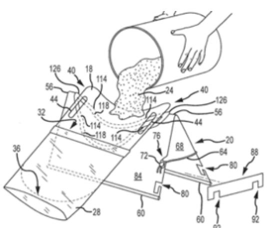


Figure 7. Device for Inserting a Food Stuff into a Pliable Bag.

This last design is called Device for Inserting a Food Stuff into a Pliable Bag. The bag rests on an angled ramp with prongs to keep the bag open. Then, the user can poor food down the ramp that will guide it into the bag, making it easy for the user to fill the bag.

2.5 Summary of Relevant Technical Literature

This section contains summaries of topics relevant to our design, such as lunar environments, geological sampling tools, and spacesuits based on review of technical literature.

<u>Tools and Technologies:</u>

The tools and technologies used during the lunar EVAs were quite robust and inefficient during the Apollo Missions. Due to the poor design of their tools and limited dexterity in their spacesuit, the astronauts had to stay together during sampling procedures because they could not perform the jobs alone [14]. This sets up a new design challenge as we want our sample container dispenser to enable astronauts to work independently, and therefore cover the most ground possible.

We must also consider the materials we will be using for our dispenser, which should be able to withstand the Lunar environment. NASA uses aluminum alloy 6061 and 300 series stainless steel, to eliminate contamination from materials such as Pb, U, Th, Li, Be, B, K, Rb, Sr, noble gases, micro-organisms, and organic compounds [17].

Radio Frequency Identification tags could also be implemented to easily trace back the samples to where they were taken from. It is important to know the origin of the samples, and their current method of keeping track of this information is not usually precise.

The Moon's Extreme Thermal Environment:

The moon's extreme thermal environment, which sees lunar surface temperatures ranging from 25 K to 390 K (-415 F to 245 F), can have important consequences on some materials [15]. These huge variances in temperatures will be a consideration when selecting the material for our dispenser, but also the manner in which we assemble it. Most sampling devices used on the moon are made of Aluminum, which has promising thermal characteristics to withstand these extreme conditions.

Additionally, physisorption could also be used as a method of probing the molecular interactions occurring at a solid surface. This method is one of the most effective bonding mechanisms, especially in the lower temperatures. We can definitely consider this technique when constructing our sample container dispenser.

NASA's New Spacesuit:

The newly designed spacesuit for the 2024 Artemis Missions, which has updated shoulder placement, allows astronauts to move their arms more freely. This enables them to easily lift objects over their heads or reach across their body in the pressurized suit. The new shoulders minimize the effort required for full mobility and include bearings that allow full rotation of the arm from shoulder to wrist [16].

It is important that we fully understand the full range of mobility the astronauts will be able to demonstrate once on the moon since dexterity is a significant design consideration. This should greatly benefit us and give us a broader range of potential designs that the astronauts would be able to efficiently use.

The Effects of Lunar Dust:

The Lunar dust found on the Moon's surface has a drastic impact on the EVA systems and tools. It has caused astronauts to struggle during EVAs and has even impeded the function of certain devices. As a matter of fact, the previous design used to dispense and contain sample bags failed due to lunar dust. NASA used Velcro to attach the container and sample bags to the portable life support system tool harness. However, the dust clogged up the Velcro and rendered it useless, causing the sample bags to fall off and even damage one of the rovers [18].

This information is crucial to our design process as it gives us a glimpse into the harsh environment of the Moon, as there were reports of equipment being clogged and mechanisms jammed in every Apollo mission due to this phenomenon.

2.6 List of Applicable Industry Standards

The following technical standard specifications are from NASA's technical standard, NASA-STD-6016A, *Standard Materials and Processes Requirements for Spacecraft.*

Table 2. List of relevant standards from *Standard Materials and Processes Requirements for Spacecraft* [19].

Standard Section	Title	Description
4.1.7	**Materials Certification and Traceability**	Outside vendors shall not heat treat, hot work, or cold work metal stock unless they create a new certification.
4.1.8.3	**Structural Fastener Design Values**	Structural fastener designs shall be defined by minimum load tests in the applicable part
4.2.2	**Metals**	If using carbon and low alloy high strength steels, yield strength must be greater than 1240 MPa in order to control stress corrosion cracking
4.2.2.1	**Aluminum**	The 5000-series alloys containing more than 3 percent magnesium shall not be used in spaceflight hardware that provides mission-critical functions where the temperature exceeds 66 °C (150 °F).
4.2.2.2.1	**Drilling and Grinding of High-Strength Steel**	Low stress machining techniques with coolant are required for drilling, grinding, reaming, or machining of steels. These practices can be found in SAE AMS2453.
4.2.2.2.2	**Corrosion-Resistant Steel**	Welded assemblies shall be heat treated and quenched except for low carbon grades such as 321, 347, 316L, and 304L.
4.2.2.7	**Zinc**	Zinc should not be used in vacuum environments, only black zinc-nickel plating is allowed.
4.2.3.7	**External Environment Survivability**	Materials must meet their intended life cycle when exposed to the following environments: *atomic oxygen, solar ultraviolet (UV) radiation, ionizing radiation, plasma, vacuum, thermal cycling, contamination, dust, planetary atmospheres, meteoroids and orbital debris.*
4.2.4.11	**Additive Manufacturing**	Parts additively manufactured need to be inspected for material properties and their macro/microstructure.

A common NDE method used by NASA is ultrasonic and x-ray inspection to detect any forms of fatigue cracking on equipment [20]. This inspection method will be implemented in our operating plan so technicians can evaluate the strength of our dispenser after a few years have gone.

3 OBJECTIVES

NASA is preparing for the upcoming Artemis missions to the moon by 2024. Their astronauts need a way to efficiently store and dispense sample bags for geological samples during lunar EVA operations. In particular, the sample container dispenser should enable astronauts to conduct sampling as a solo task accounting for limited dexterity due to the spacesuit. Our project aims to address this problem as well as the desires of our sponsor, such as the dispenser containing a specified quantity of bags, holding the bag on the dispenser while it's being filled, and focusing on the design's simplicity, reliability, and ease-of-use for astronauts who may only be able to use one spacesuit-gloved hand to operate the dispenser.

3.1 Boundary Diagram

In order to better understand the scope of this project, we developed a boundary diagram that shows our dispenser in the context of its application. This diagram is shown below in Figure 2. Our project scope is represented by the rectangular prism with a red, dashed outline. We examined the interactions it will have with other elements of the lunar surface activity. First, we show the contents of the dispenser—the sample bags themselves. The bags have already been designed by NASA, and it's essential we accommodate them appropriately. The bags will be held on the dispenser while being filled with up to three pounds of lunar surface samples. We also show the interface requirement of the four-hole bolt pattern which will allow the sample container dispenser to attach to either a tool carrier or utility belt on the astronaut's spacesuit as shown.

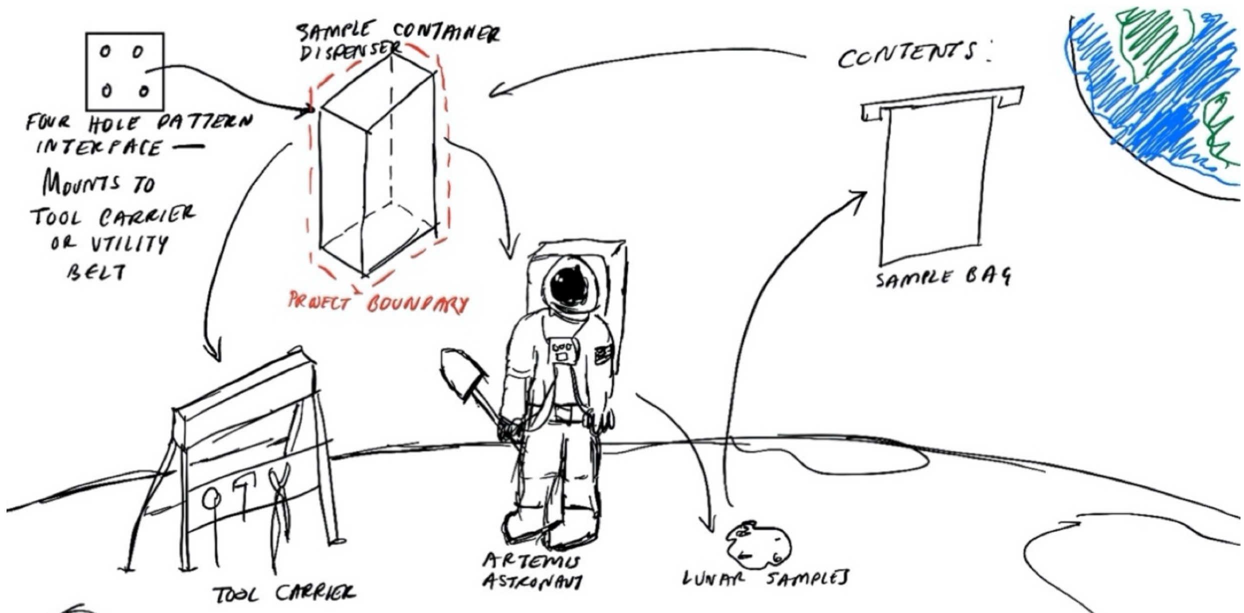


Figure 8. Boundary diagram showing sample container dispenser in its application setting during lunar surface EVA.

3.2 QFD House of Quality

In our design process, we utilized the Quality Function Deployment design technique by constructing a House of Quality. The House of Quality is visual representation that enables several elements of design consideration to be analyzed. We began by establishing who our "customers" or end-users truly are. For our project, it's important to consider the Micro-g NExT program as well as the astronauts who would use our device. We then detailed the customer requirements, identifying what they want and need from our design. This was compared against our list of engineering specifications, which are measurable ways of ensuring we met our customer needs/wants. We also were able to compare several current designs we discovered in the background research process to the customer and engineering requirements, which allowed us to identify the beneficial qualities that current solutions have, as well as their shortcomings. Additionally, the House of Quality allowed us to understand the engineering specifications we created. We quantified the target quantities or goals of testing and showed whether they had positive, negative or no correlation between one another. Our complete House of Quality diagram is attached as Appendix A: QFD House of Quality.

3.3 Engineering Specifications

Table 3 shows the engineering specifications we developed in order to meet our customer's needs. Each of the specifications was determined necessary through the House of Quality exercise discussed previously, where we also developed target values which will be used to evaluate the extent to which we met the requirements when we test our design. The tolerances indicate the extent to which it is acceptable to vary from the target values. The table also demonstrates the level of risk, or the relative level of difficulty we anticipate for meeting each requirement. Lastly, we assigned a method to evaluate whether the criteria were met, shown as A (Analysis), T (Test), I (Inspection), or S (Similarity to existing product).

Table 3. Engineering specifications table.

Spec. #	Specification Description	Requirement or Target	Tolerance	Risk	Compliance
1	Quantity of Bags Held	20	n/a	L	T
2	Sample Weight Held	2 lbs	TBR	M	T, A
3	Dimensions	12"x12"x5"	TBR	L	I
4	Mode of Operation	Manual power	n/a	L	T
5	Total Weight	3 lbs	TBR	L	I
6	Ease of Operation	n/a	n/a	H	T, I, S
7	4-bolt Interface Pattern	Match	TBR	L	T, I
8	Material Selection	Aluminum, Stainless Steel, Teflon	n/a	M	I, S, A
9	No Sharp Edges	TBR	TBR	M	I
10	Pinch Points Identified and Labelled	n/a	n/a	L	I
11	Dispense one bag at a time	1	n/a	H	T, I
12	One-hand operation	n/a	n/a	H	T
13	Protect Bags	n/a	n/a	M	T
14	Bag remains attached	n/a	n/a	H	T

3.4 Discussion of Specifications

As seen in Table 4, we identified four high-risk specifications: ease of operation, dispensing one bag at a time, one-handed operation of the dispenser, and ensuring the bags remain attached during use. These are essential functions of the dispenser and will require unique mechanisms to allow a bag to be opened with one hand then filled with several pounds of sample while attached to the container. In order to address this risk, we spent significant time on the ideation stage to develop a concept that will reliably achieve these tasks. Furthermore, it will be essential to undergo thorough testing applying realistic conditions to the best of our ability. Evaluation of these specifications is discussed further in Section 7, the Design Verification Plan.

4 CONCEPT DESIGN

With the necessary background knowledge and objectives for our device, we began our concept design process. By working through functional decomposition, ideation, prototyping, and concept analysis, we developed a concept design direction which we believed would best meet the requirements. The initial concept was a device with a compartment to store individually rolled bags, which would be maneuvered manually by grabbing the exposed aluminum flags on the rim. The bags would be positioned in a door mechanism with upward-facing hooks which would allow the bag to be opened and held while being filled. This concept is shown below in Figure 9.

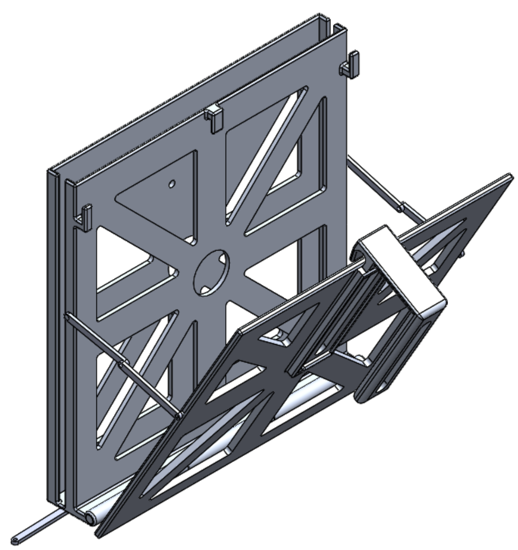


Figure 9. Isometric view of the initial sample container dispensing device concept.

4.1 Functional Decomposition and Ideation

In order to better understand what the design needed to accomplish, we performed a functional decomposition based on our understanding from the competition requirements and background research. We began with determining top-level functions that our sample container dispenser would need to achieve. Once the main functions were identified, we continued to break down the sub-functions and basic functions that would be necessary to achieve the overall purpose. Our functional decomposition tree, which was used as the basis for our ideation, is shown in Figure 10.

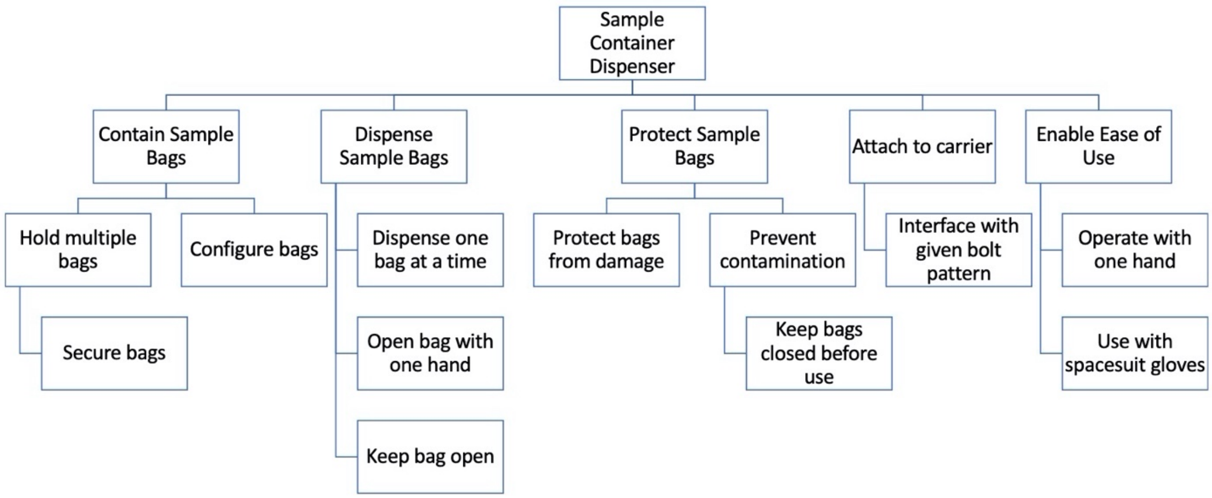


Figure 10. Functional decomposition diagram of the sample container dispensing device.

After identifying each function, we began our ideation process. We chose to do a modified form of brainwriting, where each participant spends time writing down their ideas. After a specific period, participants pass their notebooks and build on one another's ideas. However, since we were unable to perform this in person, we held several 15-minute sessions where we silently generated ideas. Most of these ideas were visual, presented as rough sketches in Appendix B: Ideation List. After each period, we shared our ideas. This naturally led us to developing new concepts based on each other's concepts. With the initial ideation complete and a collection of concepts, we began design selection.

4.2 Design Selection

We began to analyze our concepts by creating concept models that would further explore the ideas generated during the brainwriting process. These models were intended to be built quickly in order to demonstrate a single function. We each constructed five prototypes mainly from foamboard, hot glue, popsicle sticks, and other simple materials. Some of these prototypes are shown in Appendix B: Ideation List.

Once we had all of our prototypes fully built, we were finally ready to conduct some basic preliminary tests to determine functionality and feasibility of potential designs. This was necessary to get a physical understanding of the prototypes by manipulating the mechanisms so we could test the designs and determine as a group what their advantages and limitations were.

In this meeting, we were able to discuss what each prototype did well, and what could be improved upon. However, we quickly all agreed on a few concepts which we thought would work well for our specific project when considering the requirements laid out in the Objectives section. Some of the chosen concepts are shown below.

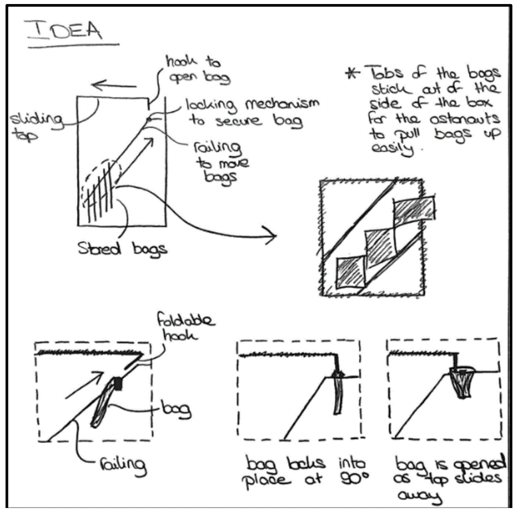


Figure 11. Diagonal railing system concept sketch.

Figure 11 illustrates a design which uses a diagonal railing system to store the bags with the side aluminum tabs exposed to the exterior. This would enable the astronauts to easily move the bags while they are being contained and position them in the proper configuration to ensure dispensing. Once the bag is pulled up to the horizontal railing system, it will lock into place as the hook is inserted inside the aluminum ring, and the bag will no longer be able to be moved any further. At this point, the user will slide the upper roof away from the dispensing edge, to open the sample bag and enable the astronauts to collect the desired sample.

The advantages of this specific design include the physical control the user has over the motion of the bags while they are being contained. This will ensure that only one bag is being dispensed at a time. Additionally, the astronaut has to lift the bag in an upwards and diagonal manner in order to configure the bag for dispensing. As the bag is being lifted, the hook's precise positioning automatically sets up the dispensing process. This removes any unnecessary extra steps the user would have to go through to properly use the device and dispense the sample bags in an efficient manner.

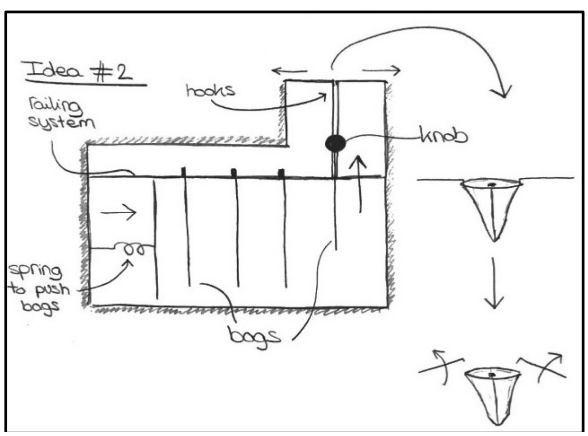


Figure 12. Vertical sliding knob concept sketch.

The design in Figure 12 uses similar components to the previous concept. However, this device would completely enclose the bags, including the side aluminum tabs, inside the container. This guarantees proper damage and contamination prevention from any exterior forces or particles. The container has a spring attached to the back wall to push bags forward and set them up for dispensing. A vertical sliding knob lifts the bag from the horizontal railing system to the inserting hooks positioned on the roof of the device. Once the knob has reached its upper limit, the knob will lock into place. The user will simply have to slide both rectangular plates away from the center of the device to open the bag and begin the sampling process. The advantages of this specific idea include the contamination prevention and the protection of the aluminum tabs.

Figure 13 below shows an additional concept sketch of a box with a door in the front. Inside the box, there are rails on which the bag rim may rest and slide. The door allows the bags to be fully covered when not in use, again addressing the contamination prevention function. The door is also connected to rails, providing a resting location for the bag which is being filled with the sample. Since the bag is in contact with the door itself as well, this may also support the bottom of the bag to prevent tearing or excessive motion.

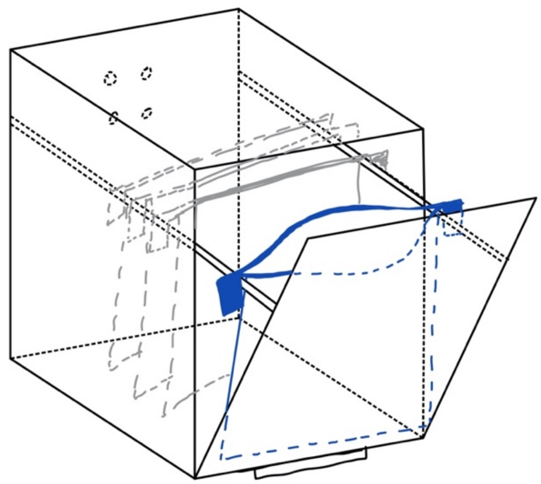


Figure 13. Door concept sketch.

In Figure 14, the rolled-bag compartment concept is shown. We developed this alternative method for storing the bags that would potentially reduce the volume required to storage. Each bag is individually rolled from the bottom up and slid into the vertical compartment. The tabs remain exposed on the outside, similar to some of the previous concepts shown, allowing for manual maneuvering. The bags would be lifted out of their compartment one at a time and placed on the rails on the outside of the container. The rails would support the bag as it is opened, and the bottom flap would support the bag as it is filled.

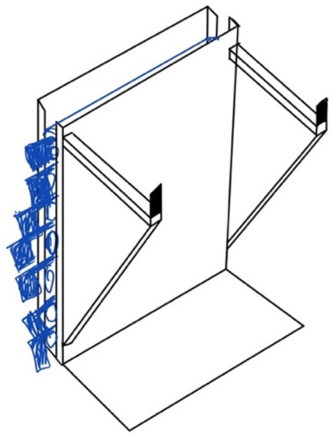


Figure 14. Vertical rolled bag compartment concept.

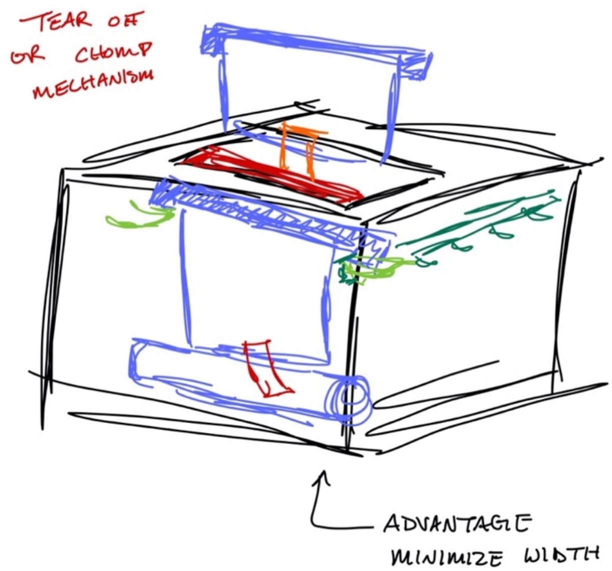


Figure 15. Vertical rolled bag in series concept sketch.

The concept sketch seen in Figure 15 illustrates the concept of storing the bags by rolling them in series. Each bag would be connected to one another by a piece of perforated tape that attaches to the end of the initial bag and to the rim of the next bag. Once the initial bag has been filled, the astronaut can easily separate the bag by tearing the perforated tape. The next bag is then in the ready position to be filled as it is held up with one-way flaps. This design idea makes is a compact method that makes it easy for the astronaut to dispense one bag at a time and to operate the compartment with one gloved hand.

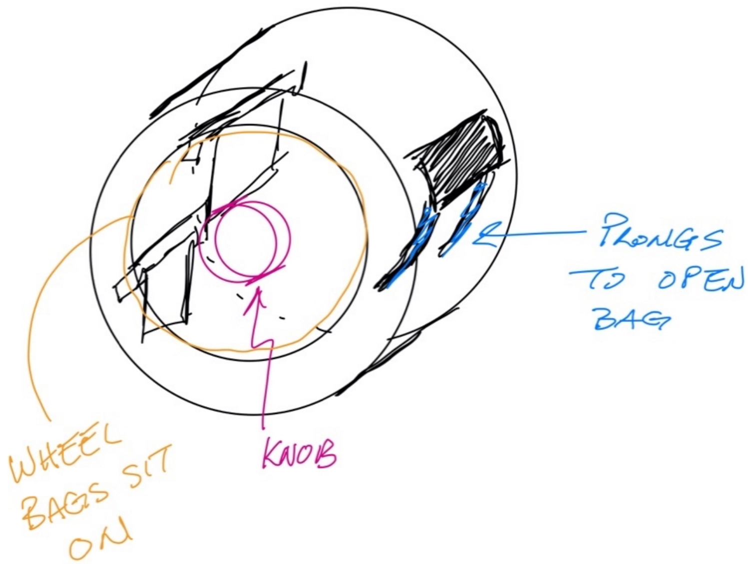


Figure 16. Bags on a wheel concept sketch.

The wheel concept in Figure 16 provides an outside-the-box design that fulfills the requirements listed by Mirco-g NExT. In this design, the bags will be stored on circular rails that can be rotated by turning a knob from outside the compartment. As the bags are turned, prongs that extend from the opening slot will slide into the bag to separate the aluminum rails from each other.

In order to begin narrowing down our concepts, we first constructed a morphological matrix, seen in Appendix C: Decision Matrices, with the engineering specifications broken down into nine main required functions for our design. Different key components from the ideation concept designs were separated into each main function. Within each function, the ideas were ranked on a color code system, with green meaning it fulfills that function well, yellow meaning it can fulfill the function, and red meaning it does not fulfill the function well. After color coding each idea, concept ideas were created by combining ideas highlighted in green across the nine main functions.

For concept selection, Pugh matrices were used to evaluate each concept's ability to achieve its respective function. The three main functions of the design that were used to create Pugh matrices are as follows: containing/protecting the bags, opening the bags, and the ability to dispense one bag at a time. In each Pugh matrix, the datum design was the existing bag holder and dispenser used in the previous Apollo missions. Each design was evaluated against the datum, with a ranking of being better, worse, or the same as the datum concept based on the listed criteria. For the function of containing and protecting the bags, the top two ideas were having the bags rolled in series and having the bags on a rail. For the function of opening the bags, the top two ideas were the scissor compression and the two degrees of freedom mechanism. For the final function of dispensing on bag at a time, the top two designs were a one-way flap and grabbing onto the aluminum tabs.

After the morphological matrix and the Pugh matrices were completed, the next step was taking the top concept designs and comparing them in a weighted decision matrix. In the decision matrix, the two criteria that were weighted the most were the ease of operation with one hand and dispensing one bag at a time. Once each design was given a score on a scale of 1 to 5 for fulfilling each function, 5 being the best, these scores were multiplied to the weight and added together. The two designs that received the highest score was the vertical rolled bag compartment design and the compartment with a hinged door design. Rather than simply moving forward with the design that scored the highest, we thought it was best to combine the two highest scoring ideas together. The vertical chamber at the back end of our dispenser, which would store the bags in a rolled fashion, was the best way to for to fulfill the containment requirement. Additionally, we also all thought the hinged rotating door with the sliding hook was the best method for meeting the dispensing requirements. By using this technique, we would ensure that the final concept met the Micro-G NExT requirements, while ensuring optimal functioning of the device.

4.3 Initial Concept Design Description

Our initially proposed concept design featured individually rolled lunar sample bags as the method of storage for the bags while not in use. Having each bag individually rolled reduces the depth of the container as they stack on top of one another. The aluminum tabs extended beyond the volume of the container through the slot on the side. The user would remove the rolled bag from the container manually by grabbing onto the aluminum side tab along the rim. This would allow for the Astronauts to have more direct control of the position of the bag. These features can be seen in the isometric views of our concept CAD model in Figure 17.

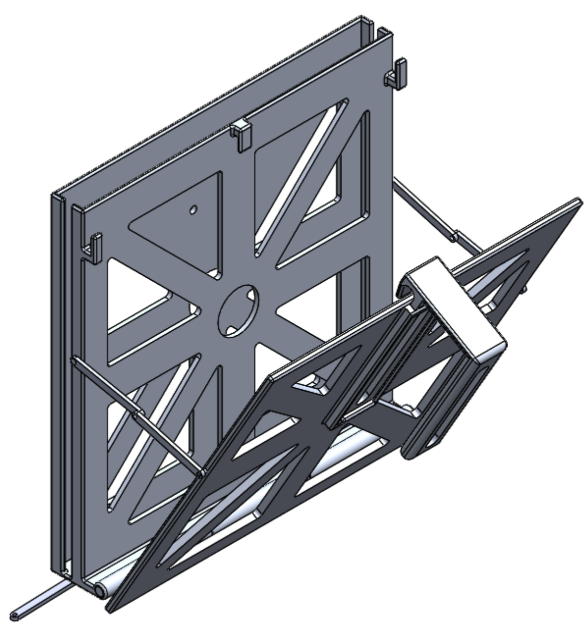


Figure 17. Front isometric view of Micro-g NExT One-Hand Operational Device (MOOD).

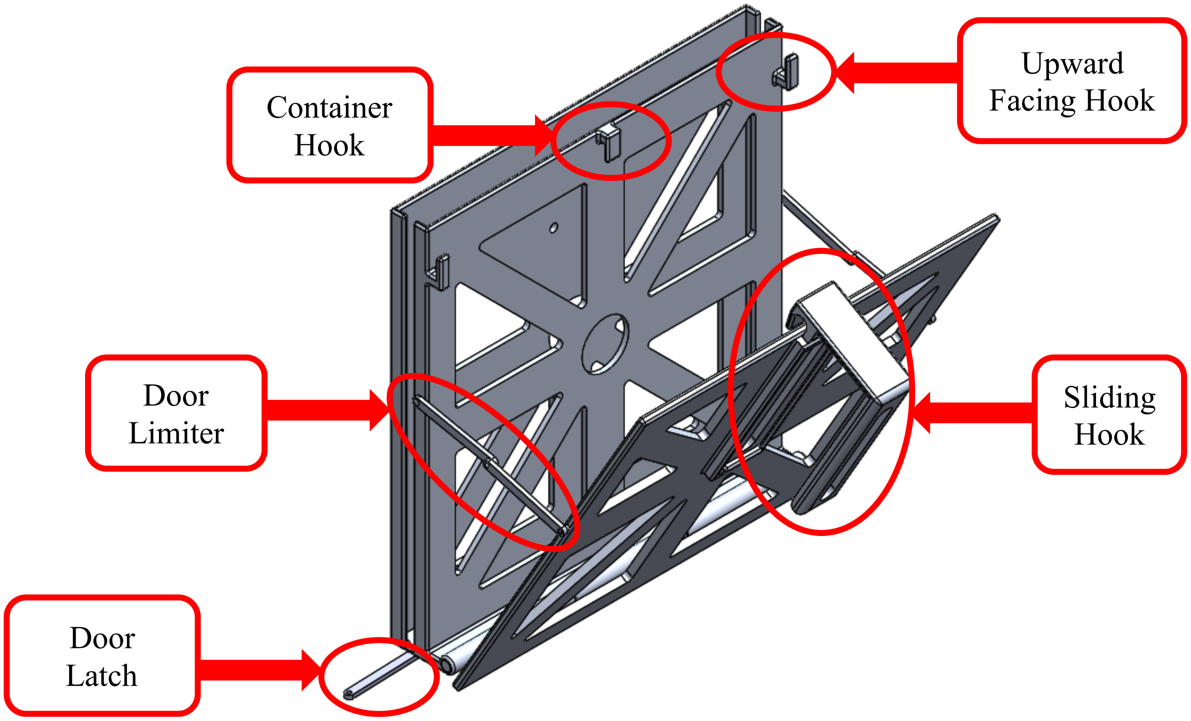


Figure 18. Annotated front isometric view of original concept.

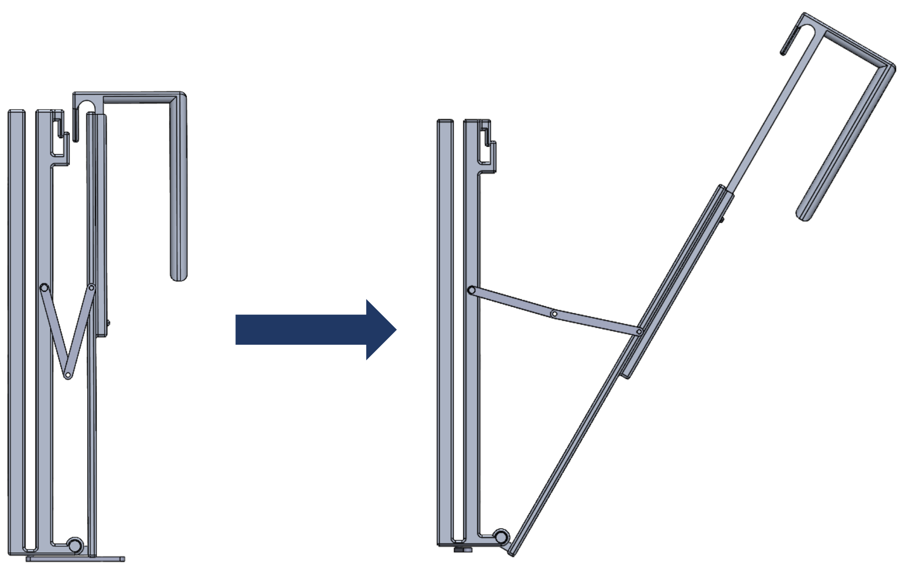


Figure 19. Left: stowed configuration. Right: the door and sliding hook extended.

On the outside of the container, would be a downward facing hook in the center, and two upward facing hooks on the sides, as indicated in Figure 18. Once the bag is removed from the container and unrolled, the bag rim would be placed on the upward facing hooks, while the center hook is inserted into the bag to hold one side of the rim in place.

The container includes a door on a hinge that functions as the main mechanism that opens the bag. On the door, there would be a sliding hook with a handle that allows for the astronauts to easily adjust the hook's position with one gloved hand. The door would be rotated in towards the bag, and the sliding hook can be placed over the rim inside the bag. By rotating the door outward, the bag's aluminum rim would be pulled apart, opening it for sampling. The hooks being inserted in the bag would be manufactured out of Al 6061 or SSTL 316L to ensure that the inside surfaces of the bags would not be contaminated. At this point, the sample bag could be filled, and the bottom of the bag would be supported by the door. The bag could be lifted out of the dispenser and sealed.

We additionally created a concept prototype that included most of the functions described above. The prototype is shown in Figure 20. Since the device does not undergo significant loads, we used lightweight, simple materials such as foamboard and wooden dowels, to construct it. These materials enabled us to build a full-scale model of the mechanisms, helping us to understand the fit and dimensions, while also allowing us to manipulate the door and sliding handle. We also created mock-ups of the sample bag which allowed us to run basic tests.

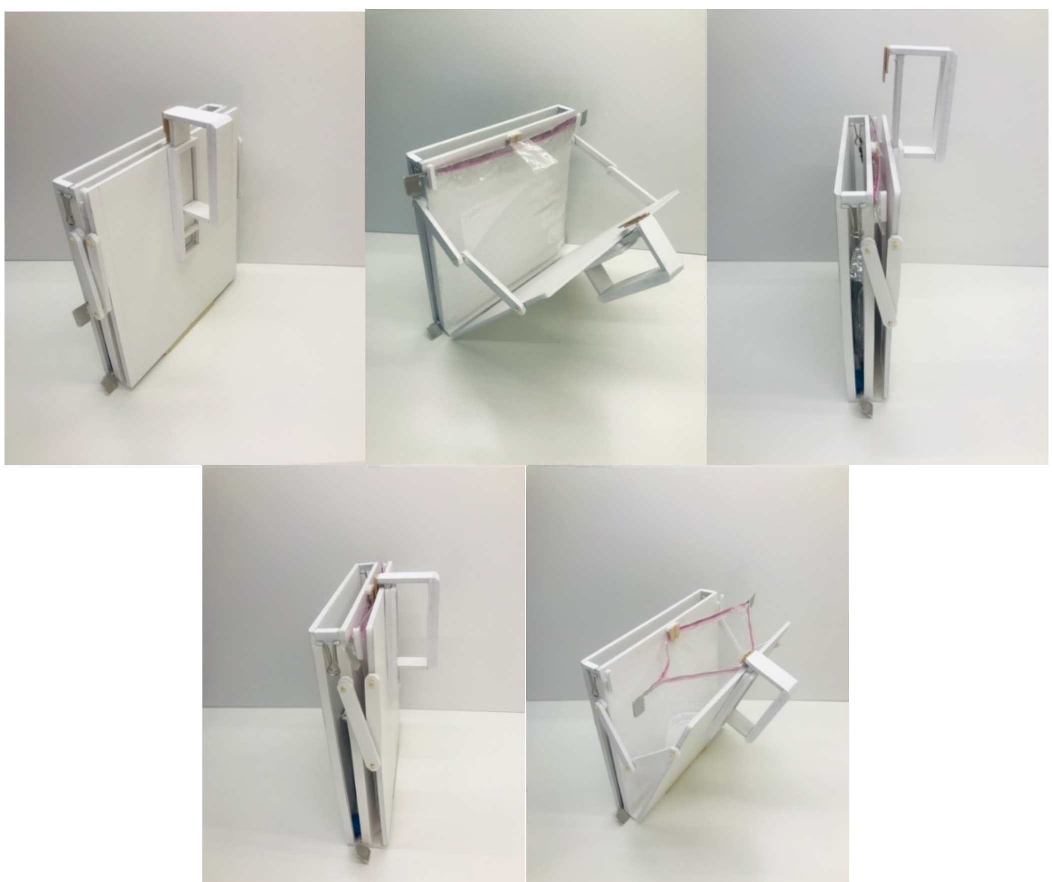


Figure 20. Concept prototype showing proposed use case. From top left: stowed configuration, bag in place, positioning hook, opening bag.

4.4 User Feedback

Once we built our concept prototype, we submitted our proposal to the Micro-G NExT committee to be reviewed. After our design was accepted, we received feedback from the NASA technical partners on our design. We also had the opportunity to meet with our mentor, NASA Systems Engineer and Project PoSSUM Scientist-Astronaut Candidate Heidi Hammerstein, to get her feedback on the design [21]. We additionally attended NASA mission briefings, during which former astronaut Dr. Steve Swanson gave a talk about EVAs and had a Q&A session [22]. With these pieces of feedback, particularly regarding space suit ergonomics, we were able to discern some key issues in our design. First, the upwards facing hooks on the outside wall of the bag container restrict the bag flag's motion and prevents the rim from being opened. When the sliding hook grabs the aluminum ring and pulls it back, the side flags are moved in a lateral and inwards direction. Thus, we realized we needed to modify our design in order account for the deformation of the aluminum rims to ensure proper opening of the bags. We also noted that our plan to have astronauts manually grab and maneuver the bags by the small aluminum tab may be difficult due to the restricted motion in the gloves.

We looked at various options to solve this issue, considering using cables and wires which would change angles as the door opens to enable the flags to move accordingly. However, we came up with a solution which not only responded to the bag's deformation constraints but would also improve the individual dispensing process. Similar to how a vending machine dispenses snacks, our new design uses a coil to displace the bags vertically and set them up to be accessible for use. Instead of having the astronauts move the bags using their hands, they now simply turn a knob which rotates the coil and moves the bags. We also decided to move away from the inserting hooks to open the bags and are now using the exterior Teflon tabs to create the clearance in the aluminum ring. Additionally, to remove the issue of the tab's displacement, we have reversed the bag configuration to have them be dispensed from the bottom instead of from the top. This means we only need upwards facing hooks to hold the bags during the sampling phase.

5 FINAL DESIGN

Our design is composed of three different sub-systems which work together to contain and dispense individual sample bags. The first is the bag container, which holds the sample bags and protects them from contaminants until they are dispensed. The second is the coil mechanism, which is housed inside the bag container. It configures the bags before dispensing, with each bag individually rolled and placed in the coil slots. The coil is attached to the lid of the bag container, where a crank allows the user to rotate the coil. Inside the bag container, four walls constrain the motion of the bags, so they do not rotate, but translate vertically as the coil rotates. This allows the user to dispense one bag at a time by rotating the coil until the lowest bag drops to the bottom surface of the bag container. Finally, a door is attached to the bag container. The door has a sliding component. A hook is able to translate along the length of the door and slider, with the motion controlled by the user who grabs onto a knob. The hook is used to grab the bag by one tab from the container, pull it out of the container, and place the opposite tab on hooks attached to the exterior of the container. Then, the door is rotated outwards, opening the bag for sampling. The full concept is shown in Figure 21.

All the components of our design will be manufactured from 6061 Aluminum as we have strict material constraints given to us by NASA, and Aluminum will provide structural strength while remaining low weight. However, we will be using high carbon steel (following NASA's approval for our material exemption) for the coil since we were unable to find any springs made out of 6061 Aluminum.

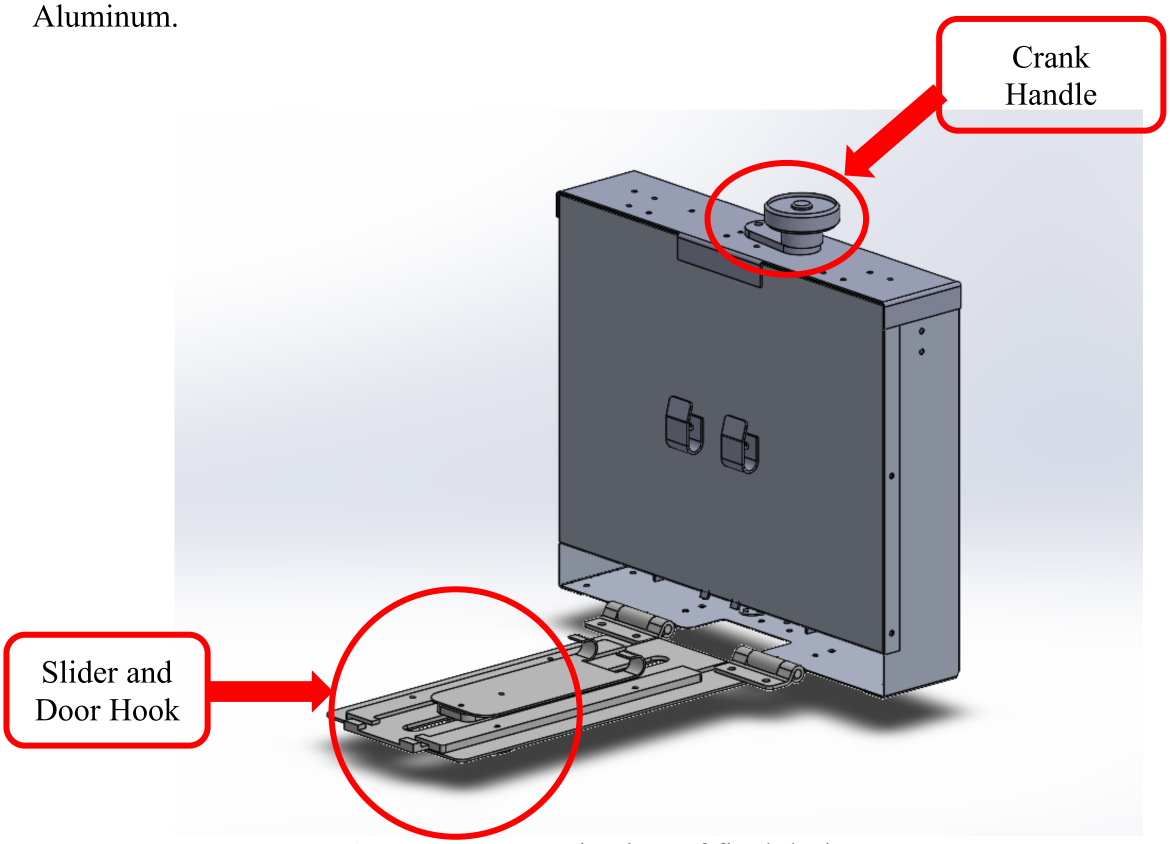


Figure 21. Isometric view of final design concept.

5.1 Bag Container

The bag container is where the sample bags will be stored. This is an enclosed rectangular structure with the top surface left open. The top lid and coil mechanism will be inserted separately. The bag container also has an open slot at the bottom of one of the side walls, alongside the widest panel, which will serve as an opening to move the sample bags from the containment configuration to the dispensing hooks. On the base of the container, there is a large notch for the bag tabs to be grabbed. This notch ensures that the sliding hook will be able to properly hook to the sample bag's attachments. The bag container is 11.625 inches wide, 10 inches tall, and 2.5 inches wide with 0.025-inch-thick walls (see Figure 22)**.** These dimensions were chosen to accommodate the bag rims, which are 11.5 inches wide.

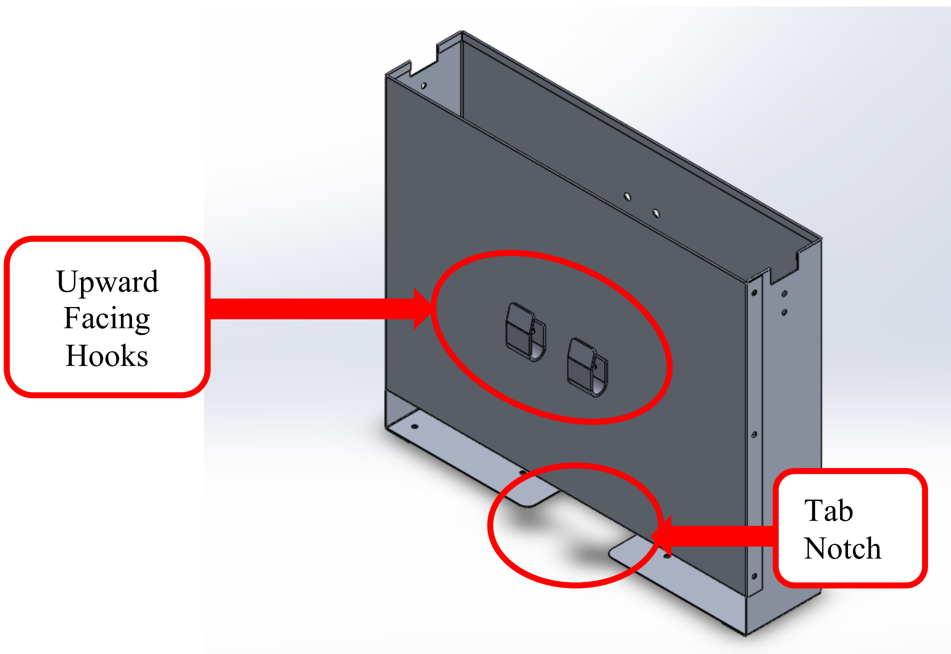


Figure 22. Bag container.

5.2 Coil Mechanism and Top Lid

The coil mechanism provides the main dispensing functionality of the sample bags while they are still in the enclosed containment unit. The bags are individually rolled and stored in the slots of the coil. A rotating crank connected to the coil sits on the top surface of the lid. By turning this crank, the coil rotates. Both components are linked with a coil holder we manufactured from AL-6061. Four walls are attached to the inside surface of the lid to guide the sample bags as they are being displaced by the coil. These walls prevent the bags from becoming dislodged or rotating as the coil moves, allowing the bags to be moved downwards in the bag container. The coil and guides end 0.8125 inches above the bottom surface of the container, allowing the lowermost bag to drop into the bottom. We have also added rails to guide the rods attached to each bag's tab to further increase the repeatability of dropping the bags in the same spot every time. This has tremendously increased the efficiency of our design as the sliding hook from the door is able to grab each sample bag correctly at every iteration. The coil mechanism can be seen below in Figure 23.

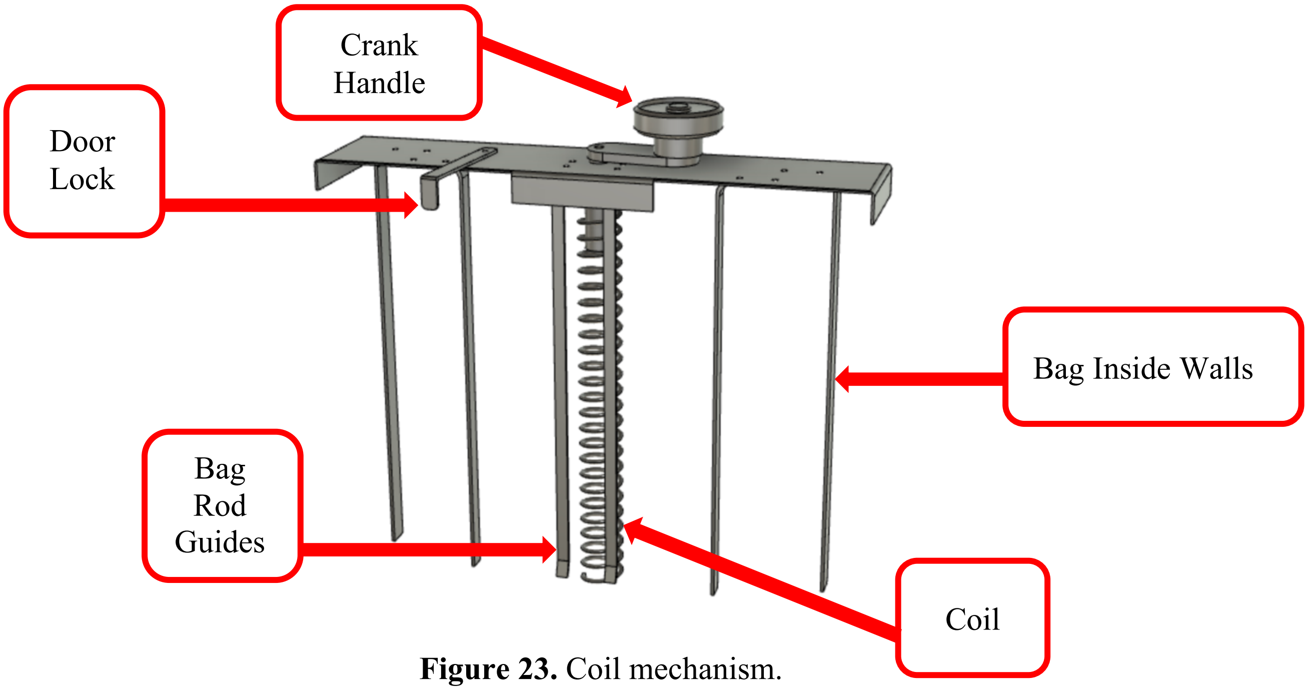


Figure 23. Coil mechanism.

5.3 Door Panel and Sliding Hook

A rotating door panel will be attached via a hinge to the base of the container. The door panel has a sliding stage, and both the door and slider have a slot. A hook attached to a knob is able to translate along this slot. It is with this sliding hook and knob that the user will be able to remove each sample bag from the container. The container begins with the door closed and the hook at the lowest point in the slider. Once the bag has been released from the coil and sits in the base of the container, the tab will be exposed due to the notch at the base of the container. The sliding hook sits slightly below this bottom surface and is able to grab the rod attached to the tab and pull the bag out of the containment unit. As the user pulls the knob outwards, the bag is unrolled, and the door is rotated outward slightly. In order to create the clearance necessary to have the second bag tab captured on the container side, the user will use to sliding rails on the door panel to lift the knob and hook past the top of the dispenser as the door is being closed. Once the door is back to a vertical position, the knob and attached bag are moved downwards and the rod attached to the opposing tab is captured inside the hooks on the container. The bag can now be opened by rotating the door outwards once more and the sampling process can begin. The door panel is 12 inches wide and 10 inches tall but with a thickness of 0.1 inch to provide additional stiffness. The door, sliding mechanism, and hook can be seen below in Figure 24.

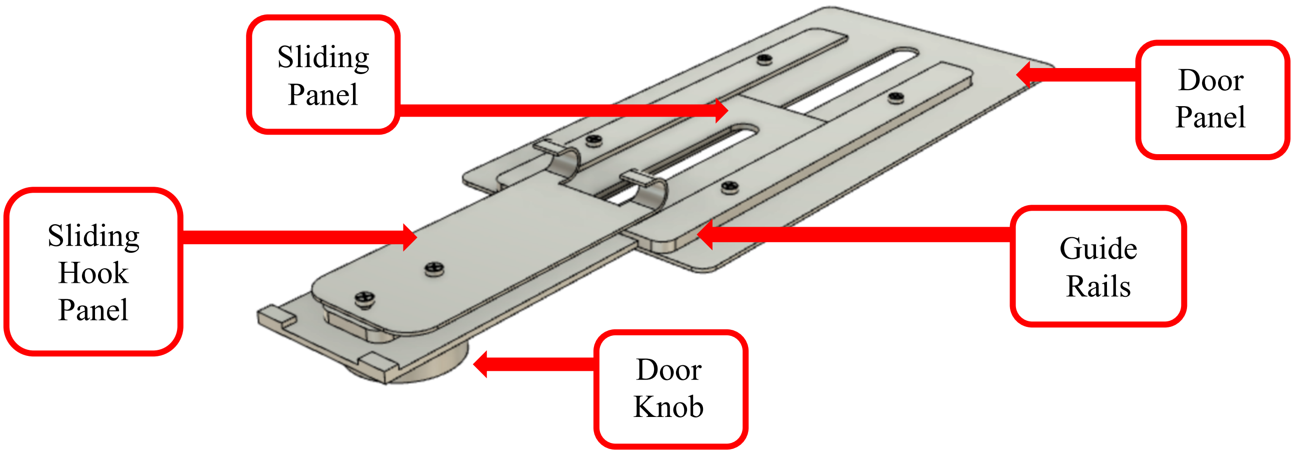


Figure 24. Door with sliding stage and hooks.

5.4 Design Justification

We made each design choice with the requirements in mind, particularly as we reconfigured our design to accommodate the user feedback we received. We focused on ease-of-use features, implementing the crank and sliding hooks with easily maneuverable handles. Other mechanical features have been proven using our structural prototype, which is shown in Appendix D: Structural Prototype. One of our main mechanisms draws inspiration from a well-know, proven concept: the vending machines. This concept performed as expected in our structural prototype, with the side panels and rods successfully constraining the bags. Thus, we were able to successfully test the coil mechanism and its proper displacement of the bags.

Our structural prototype also validated the use of rods attached to the bag's Teflon tabs. While running our tests, we were able to successfully open the sample bag by inserting the rods inside the hooks on both opposing sides, and then rotating the door. This also validated the sliding slot on which the knob is attached which correctly enabled the user to slide the hook up and above the door panel, and then back down alongside the container wall. This ensured the second rod would be securely inserted inside the corresponding hook.

The sizing of our final concept is based on the challenge requirements. This ensures the total stowed volume is within the limits of 12"x12"x5". We chose Aluminum 6061 since it complies with the specifications, in addition to its machinability. The majority of the structure is sheet metal to ensure we are below the weight limit of 3 lbs., while still providing the necessary strength and stiffness under nominal use cases. These calculations are provided in Appendix H: Analyses and Supporting Design Material.

Additionally, we compiled a MATLAB code which could be used to conduct strength and stiffness analysis to ensure the sheet metal would not deflect past 0.1 inch. We used this to validate our design of the door panel, as well as the door slot panel which can be pulled out above the dispenser. In all cases, using a thickness of 0.019 inch for the bag container and a thickness of 0.1 inch for the door, our components deflections remained well within maximum allowed threshold.

5.5 Safety, Maintenance, and Repair

Pinch points and sharp edges are the main safety concern for the final design. The previous design featured guide rails that posed the largest risk for pinch points. We have eliminated these rails entirely, which greatly reduces the possibility of the bags or the astronaut's glove getting caught on our container. Looking at the final design, the most pronounced pinch point location is between the door and the container walls. The clearance between both faces is approximately 0.85 inches, so the risk of pinching is relatively low. Furthermore, following NASA's standards, we addressed the concern of sharp edges by adding a minimum fillet radius of 0.125 inches to our design.

Maintenance and repair will not be a significant concern for our design. Our dispenser needs to withstand a cycle lifetime of 5 repetitions. The aluminum components will not be worn after this use case and will not need any significant repair. However, in case of damage, our design allows for sub-systems to be easily exchanged as they are attached by removable hinges and custom slots. The only maintenance anticipated is ensuring proper drying of the device after underwater testing.

5.6 Cost Analysis

The total cost of the system is around $595. The majority of costs for the system are resultant of raw material procurement. Due to restrictions on the choice of materials, most components were fabricated from Aluminum 6061. In order to simplify machining operations, we purchased stock close to the dimensions of the final part. About $182 of the final budget was spent at Grainger through our Micro-g NExT stipend. The remaining $413 was spent on raw materials and fasteners at McMaster-Carr.

5.7 Remaining Concerns

Our main concern revolves around the functionality of our design underwater. We have conducted tests in an apartment pool and have greatly increased the reliability and functionality of MOOD for underwater use. However, our design will be tested with sample bags made entirely from Teflon and aluminum. The sample bags we tested with were made from Ziplock bags and aluminum. We still believe the final design of MOOD has the capabilities to adapt to these changes.

6 MANUFACTURING

6.1 Parts Procurement and Budget Management

Part procurement occurred in several phases. Our budget had two components: an amount of \$500.00 was allotted from the ME Senior Project Fund, and we earned \$400.00 in stipends for components through the Micro-g NExT Competition. These budgets were independent of one another and were managed as such.

Micro-g NExT Stipends

The Micro-g NExT Stipends were to be utilized for components from Grainger Industrial Supply or outsourced manufacturing. Because we planned to do all manufacturing in-house at the Cal Poly Machine Shops, the \$400.00 in stipends we earned from completing competition milestones was directed entirely to parts procurement. After identifying the components necessary to build our first-round prototype, we found appropriate stock and hardware from the Grainger catalog. This selection was slightly limited due to the strict material constraints on our device, making it difficult to find the exact alloy aluminum for most Grainger parts. Our order list was sent to the NASA sponsor, and they placed the order to be shipped to the Mustang ’60 Machine Shops. We spent \$181.90 of the stipends on components.

Our sponsor also provided \$350.00 in stipends for a shipping container for our device to be sent to Johnson Space Center. \$158.00 of this was utilized for a Pelican Protective Case of the appropriate dimensions. The complete budget, with the sponsor-procured components identified, is shown in Appendix G: Project Budget.

Senior Project Budget

The budget provided by the Senior Project Fund was available for use at a variety of vendors. Our initial budget estimates showed approximately \$471.00 in expenses for the structural prototype, verification prototype, and testing and outreach activities. Our final spending reached the full \$500.00 budget, though the distribution of the expenses changed slightly. We had to increase the expenditure for the raw materials, mostly due to the materials requirements which led us to purchase aluminum 6061 stock, stainless-steel fasteners, and expensive Teflon spacers. However, we lowered other expenses since we did not have to outsource manufacturing time to the student machine shop technicians and were able to repurpose some items for the testing equipment. We also were able to achieve our outreach lessons on a much lower budget due to modifying the activities based on feedback we received.

Most of our material purchases were through the ME office pro-card. The majority of raw material and hardware came from McMaster-Carr. We also made material purchases from Home Depot and Aircraft Spruce. A few purchases were made individually and reimbursed, such as paying a peer with a 3D printer to produce a few prototype components. All expenses were budgeted for and tracked through a spreadsheet identifying the order dates, components, subtotals and shipping/tax costs, which can be seen in Appendix G: Project Budget.

6.2 Manufacturing Processes

All manufacturing was conducted by our team members at the Cal Poly Student Machine Shops using a variety of techniques. Most of our parts were aluminum sheet metal and stock, allowing for many opportunities to utilize both familiar and new techniques to create the components. In order to manufacture these components, we referred to our manufacturing plan described below and the engineering drawing package in Appendix F: Drawing Package.

6.2.1 Bag Container

The four sides of the bag container have been cut out of a 0.025-inch-thick aluminum sheet from Aircraft Spruce using a water jet. We used the water jet to cut out the sheet metal flat pattern, which is approximately a rectangle the size of 12 inches by 30 inches. The flat pattern includes a four-hole bolt pattern which will be used to attach the space suit adapter to our device. Once we cut the piece, we used a brake to bend the pattern and form the four walls of the container. The sheet metal pattern includes tabs which have been folded over to form hems, which reduce sharp edges, one of our design's main hazards.

The remaining edges that coincide have additional tabs which were folded in order to form the container. The bottom base has a length of 11.75 inches and a width of 2.875 inches. The bottom also has a cutout which is 3 inches in length and 0.75 inches deep, located along the center plane and at the bottom edge. Once this piece was cut and the edges had been filed to remove burs, it was bent together and secured with 1/8" aluminum pop rivets so that the structure will not unfold. The pop rivets were not the appropriate alloy of aluminum but was approved by the NASA technical partner for use.

6.2.2 Container Lid Assembly

Lid

We used the water jet cutter to manufacture our lid from 0.05-inch-thick 6061 Aluminum sheet metal stock we purchased from McMaster-Carr. The dimensions of the lid are 11.75 inches by 3 inches. The lid has tabs on each side of the rectangle which will be folded 90º to align and properly close the top of the container. A ¼-inch clearance hole is located in the center of the lid, which is used to secure the coil assembly to the lid.

Using a brake, we bent the lid's tabs. On the side tabs, we mounted the hook-side of a draw latch which is attached on the side of the container outside wall. The draw latch captures the hook on the lid and secures it to prevent any motion. Stainless steel draw latches were chosen to close the lid to reduce the need for threaded fasteners. The lid also has several attachments. See the section below for the Alignment Walls

Coil and Coil Insert

The coil was sourced from Grainger with our NASA stipends. The coil is made from stainless steel and has an overall length of 12 inches with 3.25 coils per inch and an outside diameter of 0.844 inches. In order to secure the coil, we manufactured an insert which clamps the coil in place and links its motion to the rotation of the crank handle attached to the lid. We used a 1-inch piece of

1-inch diameter aluminum rod stock, which we then turned on the lathe to a 0.8-inch diameter to clearance fit inside the coil. We then added three holes to our insert: a ¼-20 tapped hole at the top which would be used to attach the coil to the lid crank, and then two 8-32 tapped holes on opposite one another on the cylindrical face of the insert. These two holes retain inserts bolts with washers which will tighten over the coil to keep it in place. This lathe operation is shown below in Figure 25.

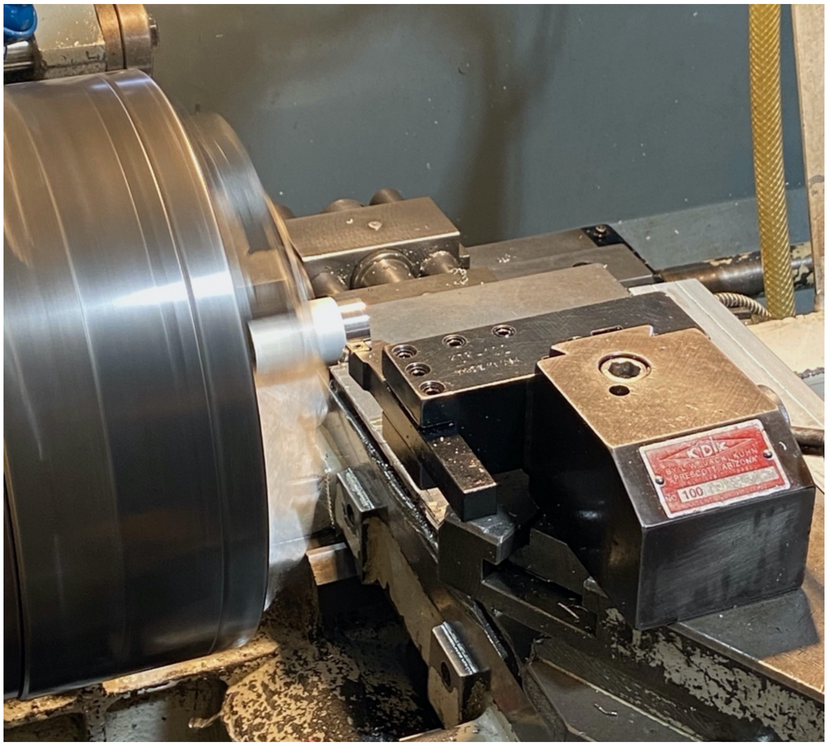


Figure 25. Lathe Machining of the Coil Insert.

Alignment Walls

We used 0.064-inch-thick Al-6061 sheet metal stock to manufacture four alignment walls to constrain bag motion in the coil. Using the sheet metal stomp shear, we cut strips of approximately 1-inch in width. We then bent each strip at about 1.5 inch from the edge to a 90-degree angle. We drilled two 9/64" holes in each 1.5-inch bend which were used to attach the inside walls to the lid using rivets. We also used two additional strips that were almost identical in size. However, we place these in a v-like formation around the coil to keep it aligned while it is rotated. Although the inside walls have shown their usefulness and effectiveness, we need to refine our positioning of the walls to maximize their efficiency.

Door Lock

The door lock is made from two small strips of 0.064-inch-thick AL-6061 sheet metal stock. The door lock includes the rotating arm attached to the lid via a single rivet, as well as a strip attached to the top of the main door panel, on the outer side. The rotating strip is about 3 inches in length and 0.25-inch wide, while the stationary strip on the door is about 2 inches long, with the same width. Both strips have a 90-degree bend of 0.3 inches long to enable them to interlock and keep the door closed.

Crank Arm

The crank arm was made using 0.187-inch-thick Al-6061 sheet metal stock. We used the vertical bandsaw to cut it down to 2 inches in length and 1 inch in width. Using a sander, we removed the sharp edges and replaced them with smooth curves. Finally, we added a 0.25-inch clearance hole and a ¼-20 tapped hole on opposite ends of the crank arm. The clearance hole will be used to attach the crank arm to the coil while the tapped hole will be used to attach the crank handle.

Crank Handle

The handle is 1 inch in length and 1 inch in diameter, however following testing the diameter is likely to increase to improve ease-of-use. The handle has been cut on a bandsaw from a 1-inch diameter 6061 aluminum stock. Using the lathe, we added chamfers on both sides of the handle to remove sharp edges. We have also added a ¼-20 tapped hole at the bottom of the handle which is used to attach the handle to the crank arm.

6.2.3 Door Assembly

Door Panel

The door panel has been water jet cut from 12”x6”x0.064” Al-6061 stock. The water jet removed material to create the middle slot which is centered along the part and is 0.5 inch in width. It also cut our stock to the proper dimensions of 5 inches wide by 10 inches long. Finally, we were also able to remove sharp edges by creating fillets and rounding out the cuts.

To enable the other door components to be attached to the main door panel, we have added a four-hole pattern of 8-32 tapped holes. The holes are 1 inch away from their respective side edge. The two top holes are 2 inches away from the upper edge and the two other holes are 4.5 inches away from the top holes respectively. The top edge of the door panel was also sanded to create a slight taper, which allows for the door’s sliding knob to better travel along the length of the slot.

Door Knob

Using a cylindrical blank of diameter of 2 inches and a thickness of 1 inch, we used a mill to remove a 1.25 inch by 0.85-inch rectangle of material positioned in the middle of the knob stock. The purpose of this operation is to reduce the weight of the part. We then drilled two holes respectively 0.25 inches away from the 1.25-inch side of the removed rectangle. These holes are centered and tapped to fit 8-32 bolts. We have also used a lathe to remove sharp edges, face the ends flat, and introduce chamfers. An image of the mill operation is shown below in Figure 26.

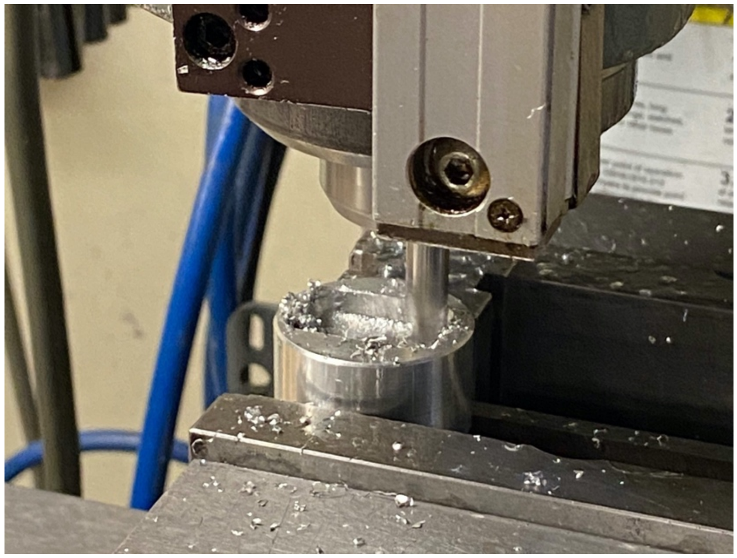


Figure 26. Mill Operation to Manufacture the Door Knob.

Door Sliding Panel

The door sliding panel was water jet cut from 0.187-inch-thick Al-6061 sheet metal stock. By using the water jet cutter, we were able to cut our part to its proper dimensions of 2.5 inches wide by 10.25 inches long. We were also able to obtain the center slot which is 8 inches long and 0.5 inches wide.

Following the water jet operations, we place our part on the mill and faced off 0.087 inches. However, we left four small rectangles at the full 0.187” thickness to create four stoppers which are crucial in ensuring the slider works properly. Two stoppers are placed at the top of the part, with a width of 0.5 inches starting from the side edge, and a height of 0.25 inches relative to the upper edge. The two other stoppers are positioned 5.25 inches away from the upper edge. Unlike the other stoppers, these two are 0.25 inches from the side edge and are 0.25-inch squares. This part posed a particular challenge on the mill due to the unique fixturing necessitated by the significant amount of material being faced off the top surface.

Slider Guides

The slider guides were manufactured from 0.187-inch-thick Al-6061 sheet metal stock, which we cut to 2 inches wide and 8.5 inches long. We then placed our part in the mill and faced off a center slot that was 0.1 inches deep and 1 inch wide. Since both slider guides are symmetric, we can make both parts from a single piece of stock.

Using a vertical bandsaw, we cut the part in half along its length, splitting the slot and leaving us with two symmetric parts. We then placed each individual guide back in the mill, but this time setting it along its length, with the slot facing upwards. Using this configuration, we were able to face off ¼-inch of material alongside a length of 8.25 inches. This created the L-shape part which we needed in order to limit the sliding panel with its extrusions. The setup was mirrored for the other slider guide.

Sliding Hook Panel

The sliding door panel is manufactured from 0.064" Al-6061 sheet metal stock which was cut to 2.5 inches wide and 5.5 inches long. We used a combination of the vertical bandsaw along with a Dremel rotary tool to obtain the middle slot. The two legs created by the slot are bent to create the door-side hooks. Therefore, we used a 3/8-inch bolt which we clamped down on to a table with the panel to create the curved hooks. By lightly tapping the part with a ball-peen hammer and rotating it 90-degrees, we created a first bend. Then by replacing the bolt and clamp, we completed the hooks 180-degree bend. Finally, using the drill press we added two 11/64" holes centered along the width, with the holes are vertically aligned to allow for 8-32 screws to pass through and attach the hook panel to the door knob. The top hole is a ¼ inch away from the upper edge, and the second hole is 1.3 inches directly below.

6.3 Manufacturing Challenges and Lessons Learned

From manufacturing our components, we learned about fastening techniques for sheet metal, how to design a part in SolidWorks for sheet metal bending and got comfortable using a manual mill and lathe. We learned to create certain fixtures to adapt to changes we needed to make throughout the building process. For example, the hook panel for the door had two rectangular extensions that needed to be bent inwards to create our hooks. In order to bend the sheet metal without it cracking, we secured a bolt in a vise and bent the extensions around the bolt. We also learned that it is always a good idea to get a head start on manufacturing your components. Overall, our parts took longer to manufacture than we planned for. Accidents happened and it took time designing fixtures and assembling the components together. Ultimately, we were able to stay on schedule by increasing the quantity of hours spent in the shops.

Recommendations

In the future, we recommend using CNC mills and lathes to manufacture the components. This allows for part dimensions to have tighter interfacing tolerances. The tighter tolerances between components would help decrease the amount of wiggle room in components like the sliding door and the crank assembly to allow for smoother operations. We also recommend using aircraft grade flush rivets to reduce stick out points in the design. Reducing the stick out points will reduce possible locations the astronauts can get their suit caught on.

7 DESIGN VERIFICATION

In this section, we discuss the methodology utilized to verify that MOOD meets the specifications. First, we examine the technical requirements and compare them to functions in our device. Then, we describe the testing and analysis performed and the outcomes from these tests. We focused on underwater testing to match the environment in which our device will be tested. Our NASA mentor, Heidi Hammerstein, provided advice and feedback for the development of these test procedures.

7.1 Technical Requirement Verification

Our design was based on requirements provided by NASA Micro-g NExT for the Sample Container Dispensing Device challenge. These requirements are shown below in Table 1. Many of our design choices were made with these requirements in mind. Ultimately, we met all technical requirements.

Table 4. Technical Requirements Table.

Requirement	Function
The dispenser shall hold 20 sample bags.	Length of coil allows for 20 sample bags to be stored in the container. However, ideal functionality for 20 bags would require an increased coil length.
The dispenser shall allow the crew member to use one hand to open a single sample bag while attached to the dispenser.	The door knob needs one hand to operate and will open the sample bag when moved outward.
The dispenser shall allow the crew member to use one hand to dispense a single sample bag at a time.	The crank handle needs one hand to operate. When turned it will dispense the sample bags.
The dispenser shall restrain the sample bags enough to prevent bag damage, deformation, or accidental opening when not in use.	The bag container fully encloses all bags when not in use. Bags are rolled to prevent contamination.
The dispenser shall be capable of holding an open bag that will be filled with a sample (up to 2 lbs.) prior to dispensing the filled bag.	The bag rests on the edge where the door panel and container meet, which can support 2 lbs. of weight.
The device shall use only manual power.	Dispensing and sampling are performed by manually turning and grabbing components.
The device shall fit within a volume 12”x12”x5”.	The device overall dimensions are 12”x11.75”x4.25”.
The device shall have a 4-hole bolt pattern to interface with the Utility Belt.	The 4-bolt pattern is on the back face of the container.
The device must be operable with EVA gloved hands.	Testing with gloved hands was performed in to verify this requirement.
The total weight of the dispenser should be less than 3 lbs, not including sample bags.	The weight of our device is 2 lbs. 14.3 oz.

The device must not have holes or openings which would allow/cause entrapment of fingers	There are no holes that would cause entrapment of fingers. We have also clearly labeled safety hazards with yellow tape.
The device should be made from only Al 6061, Al 7075, Stainless Steel (any series), or Teflon.	The device is assembled using Al 6061, Stainless Steel, and Teflon, along with approved material exemptions.
There shall be no sharp edges on the tool.	We filed down and sanded sharp edges to mitigate risk and clearly labeled sharp corners with yellow tape.
Pinch points should be minimized and labeled.	Pinch points are labeled using yellow tape.

7.2 Test Procedures Overview

We performed two main types of tests to verify the functionality of our design. First, we conducted dry (out of water) testing for a short period. This testing of MOOD's functionality was simply under Earth's gravity. We tested the main mechanisms (coil, door hooks, container hooks) while taking notes with our observations. The second set of tests was more significant since it replicates the underwater environment in which the NBL Divers will be testing our device. This also was the most challenging environment to successfully operate our device, therefore if it was successful underwater, it would most likely be successful under Earth's environment, and hopefully under lunar conditions as well. Lastly, we conducted inspections, both for requirements and safety focused. In Table 5 below, we present the tests conducted as well as the dates.

Table 5. Testing Schedule Overview.

Date	Test
5/8/21	Terrestrial Functionality Testing Initial Inspections
5/9/21	Underwater Testing
5/11/21	Underwater Testing
5/13/21	Underwater Testing
5/14/21	Underwater Testing
5/15/21	Underwater Testing
5/17/21	Underwater Testing
5/18/21	Underwater Testing Safety Inspection
5/19/21	Underwater Testing
5/20/21	Underwater Testing Final Inspections

We were able to use a local community pool to test underwater which enabled us to perform twelve underwater tests over fourteen days. The underwater testing was documented with a GoPro camera borrowed from the Cal Poly Library as we cycled through the full bag loading, dispensing, and opening procedure as outlined in the test procedures in the Appendix. Below we have included Table 6 from one test day along with our notes describing our observations, modifications, and conclusions. After each day, we used our observations to note any modifications and improvements to be made between tests. A picture from our underwater tests is shown below in Figure 27.

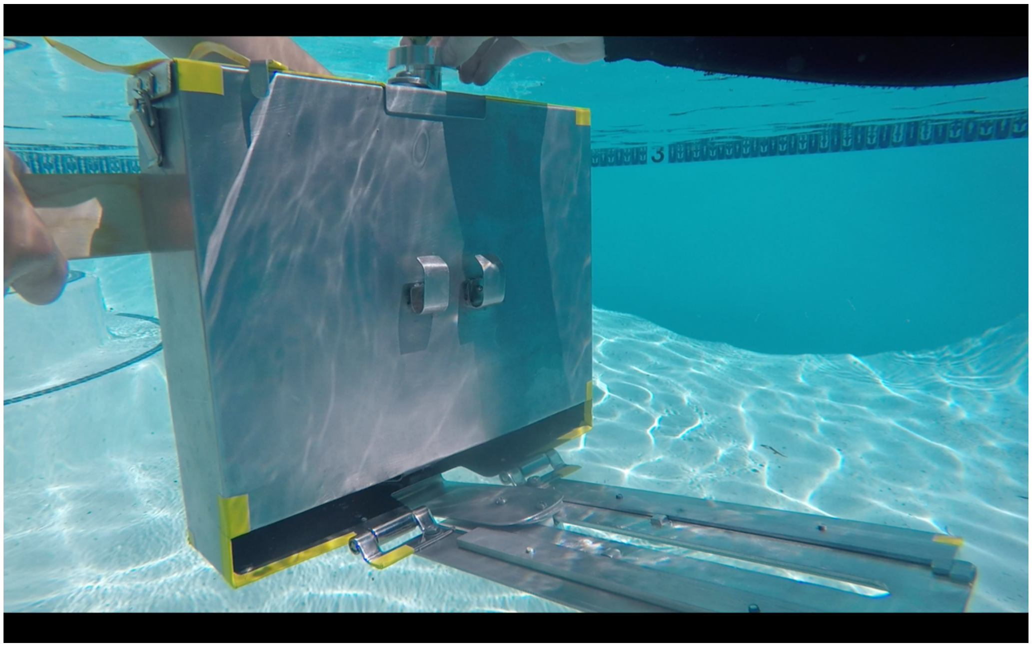


Figure 27. Underwater testing operations.

7.3 Underwater Testing Sample Data from 5/14/21

Changes made since last test date:

- Replaced aluminum rods with steel rods
- Added the Teflon spacers
- Added coil alignment walls to the bottom of the container
- Slightly bent the container and door hooks in to constrain the rods

Table 6. Underwater Testing Data and Notes from 5/14/21.

Run	Dispense	First Hook	Second Hook	Notes
1	Pass	Pass	Pass	First hook had little trouble but recoverable
2	Pass	Pass	Fail	Second rod got caught inside the bag and was too heavy to flip out. Will try slowing down operations and pressing the rim together
3	Pass	Fail	Fail	Bag rod came out at an angle, slipped between the two hooks. The second hook didn't grab because either the tabs were too long and/or the container hooks were too high and/or the bag rim opened about an inch.

4	Pass	Fail	Pass	Shortened short tab between tests. Rod came out diagonally and fell through the hook panel. After manually replacing it, the second rod placed easily.
5	Pass	Pass	Pass	Added tape to the slot of the hook panel to prevent rod from passing through. Seemed like it helped but it also came out off-center.
6	Pass	Pass	Fail	The tape seemed to help correct a crooked rod. The bag dispensed slightly rolled and floated up because there was a little air in it preventing the second rod from being captured.

Observations:

- So far, we have been able to use MOOD with one hand
- Need to add a 90-degree door stopper
- Need to replace the sliding hook panel to prevent rods from dropping down
- Need to smoothen out the center door slot for ease of use
- Need to make more bags to increase testing procedures
- Need to add easy handle to door lock for accessibility

Conclusion:

- 2 out of the 6 test runs were successful

7.4 Testing Results Summary

Over the course of these tests, we were able to drastically improve all of the main functions of our device based on our observations. In the final days of testing, we were able to successfully dispense 5 bags in a row while underwater. A summary of results for each day of the three major functions is shown below in Table 7 with the quantity of passes and fails for that day's tests. One run is considered one complete bag dispense and open cycle.

Table 7. Testing Summary with quantities for Pass (P) and Fail (F).

Date	Dispense	First Hook	Second Hook
5/9/21	11P, 6F	10P, 7F	1P, 16F
5/11/21	3P, 2F	3P, 2F	0P, 5F
5/13/21	5P, 0F	2P, 3F	0P, 5F
5/14/21	6P, 0F	4P, 2F	3P, 3F
5/15/21	1P, 3F	1P, 3F	1P, 3F
5/17/21	5P, 1F	4P, 2F	4P, 2F
5/18/21	7P, 0F	7P, 0F	5P, 2F
5/19/21	15P, 0F	15P, 0F	11P, 4F
5/20/21	10P, 0F	10P, 0F	6P, 4F

Some of our main observations and modifications included using steel rods instead of aluminum, coupled with the longer coil aligner and an extended coil holder, which greatly increased the performance of MOOD. We also we ran into a consistent issue which involved the second rod placement. This is likely because we are using prototype bags which have gone through multiple test runs, during which the aluminum rims have become deformed. Therefore, as the first rod gets pulled, the second rod would fall in the opening of the sample bag, making it inaccessible to the container hooks. However, we did notice that this error was salvageable as we were still able to get successful runs by moving the door knob up and down until the second rod came out of the bag. To counter this issue, we thought of the second set of hooks which would be upside down, positioned just below the original container hooks, pictured below in Figure 28. The new hooks would be able to grab the second rod inside the bag and lift it outwards. This would ensure the second rod is always accessible, regardless of the bag deformation.

Figure 28. Added hooks to address rods being entrapped in bag opening.

We learned a lot about our design from testing underwater. Throughout the testing process, our device worked well while testing out of water, however, the results we got from the underwater test were far different. We ran into multiple issues which had not been observed during our initial testing period. Most of them were a result of buoyancy which caused the bags to float or be displaced during the dispensing process. To counter to effect of buoyancy, we replaced our aluminum rods with stainless steel rods in order to add weight to our bags. This could likely be switched back to aluminum rods for any use out of water in order to save weight. The new rods improved the functionality of our design as they were no longer be dislodged from the hooks while the door knob was being moved around. We also noted that certain procedures could be utilized, such as loading the bags underwater after removing the air pockets, in order to further improve performance.

Another issue was identified with the sliding hook panel. The original design had a slot between the two hooks, but we noticed this allowed for the bag rod to fall between the hooks. We re-made this hook panel with no gaps while also widening the gap between the hooks. This modification alone drastically changed the consistency with which we were able to successfully grab the first bag rod.

We also realized the visibility was limited underwater as the user observed that it was hard to know when the bag had actually dropped and so was ready to be dispensed. We solved this with several modifications. The first change was extending the coil holder by an inch, lowering the coil and allowing the bags to remain in the coil for a longer amount of time. We also added inside walls for the rods to ensure they consistently dropped in the same location at every run. This not only improved efficiency but it also meant the user could now grab the rod while the bag was still in the coil and pull the sample bag out of the container by grabbing the first rod and moving the door knob outwards.

7.5 Design Verification Lessons Learned and Future Plans

With a large quantity of tests performed, we obtained approval for the sign-off of our final design verification prototype by our faculty advisor. Throughout this long and rigorous test process, we truly understood the importance of testing in the design process. This was exemplified through the drastic improvement in performance as a direct result of our testing and observations. We went from having about 1 in 17 completely successful bag dispenses, to achieving 5 successful dispensing cycles in a row, which is how many runs will be performed in the NBL.

Even with these successes, we identified several areas where further improvements could be made. However, our device has already been sent to Johnson Space Center for testing. Given additional time, we could further iterate to improve ease-of-use. Even without the device in hand, we will improve our documentation and user instructions using a former iteration of the prototype. This will aid in practicing verbal communication and instruction with the NBL divers, which will be done real-time during our testing on June 15, 2021.

8 PROJECT MANAGEMENT

We successfully completed the design, build, and test phases of the project. Our VP has been passed on to our sponsor for testing at the NBL on June 15, 2021. Results of our own testing so far have been presented in this report as well as our online expo website. In order to achieve this project, we followed a detailed schedule to ensure adherence to milestones and deadlines. A table of important milestones is shown below, and an updated Gantt chart project schedule is included in Appendix L: Gantt Chart.

Table 8. Key project milestones and deliverables.

Date	Milestone/Deliverable Description
Fall Quarter 2020	Conceptual Design Phase
11/10/20	PDR
Winter Quarter 2021	Detailed Design Phase
2/9/21	CDR
3/16/21	Manufacturing Begins
Winter/Spring 2021	Micro-g NExT Outreach Events
4/29/21	VP Sign-Off
04/29/21 – 05/25/21	Testing and Iteration
05/25/21	Ship Device to Neutral Buoyancy Lab
06/04/21	Senior Project Expo
06/04/21	Final Design Report Submission
06/08/21	Micro-g NExT Test Readiness Review
06/15/21	Micro-g NExT Remote Testing Week
07/08/21	Micro-g NExT Final Reports (Technical and Outreach) Due

8.1 Activities Overview

Given the environment with COVID-19, we implemented additional strategies to maintain strong team communication and track deadlines. Prior to conceptual design, we created a OneDrive repository with an organized file system which all members had access to. We also utilized a OneNote Notebook which allowed us to organize sketches and meeting notes. These foundational elements proved extremely useful throughout the life of the project. Similar methods would be recommended for future work.

The first phase of the project was ideation and conceptual prototyping. Our team implemented several traditional brainstorming techniques, accumulating a large number of sketches to address various requirements. We eventually utilized decision matrices to identify the best design direction. However, the design that resulted from this process was still insufficient in some respects. This was mostly due to not having user feedback prior to acceptance in Phase 2 of the Micro-g NExT Challenge, at which point we were able to interact with our mentor and technical experts. Despite this, creating physical prototypes from foam board and popsicle sticks created valuable representations of our ideas and better understanding of our challenge.

Once we settled on the final design direction, we created a structural prototype to ensure the main concepts of our design would function as intended. We focused on proving door functionality through the to-scale, foam board structural prototype. Then, with detailed design complete, we began part procurement and manufacturing of the verification prototype. As outlined in Section 6, we executed all manufacturing operations in-house at the Cal Poly machine shops. We inspected and assembled the components to proceed to the testing phase.

Our testing took several approaches. Because our final device will be tested in NASA's Neutral Buoyancy Lab, we conducted our own underwater testing to ensure device functionality in the water. We also conducted limited testing on land for structural stability under a nominal use case, as suggested by the Micro-g NExT challenge. The results of our testing were immediately analyzed to determine modifications to improve functionality. This iterative process lasted for about three weeks and became one of the most impactful and essential portions of the project.

Additionally, conducted outreach activities to our local community as part of the NASA Micro-g NExT competition. We connected with San Luis Obispo Classical Academy to guest-teach four science lessons that relate to both their curriculum as well as our project. We taught two 9^{th} grade earth science classes as well as two 12^{th} grade physics classes. This was an exciting and meaningful experience for our team and the students.

8.2 Funding and Budgetary Statement

Shown below in Table 9 is an outline of our budget. As mentioned in the manufacturing section, we received funding from the ME Senior Project Funds ($500) as well as stipends for materials through Micro-g NExT. Bolded items indicate costs covered through Micro-g NExT stipends. Most purchases were made through the Pro-card system and were tracked in our detailed budget found in Appendix G: Project Budget. We were able to remain within budget for all activities.

Table 9. Estimated Budget.

Items	Cost
Materials and Manufacturing Costs	
Structural Prototype	
3D Printed Components (time and material)	$51.00
Verification (Final) Prototype	
Grainger Raw Material	**$181.99**
McMaster Raw Material	$413.43
Travel/Shipping	
Hardware Shipping	
Pelican Shipping Container 16"x13"x6.75"	**$159.00**
FedEx, San Luis Obispo, CA to Houston, TX	
Package Estimate 10 lb, 20”x15”x10”	**$100.00**
Other Expenses	
SLOCA Outreach Activity 2 (Space Mission Physics & Moon Lander Activity) Materials Lander Kit - $3/student x 5 students	$15.00
SLOCA Outreach Activity 3 (Interactive Astronomy) Materials Quadrant Kit - $0.50/student x 16 students	$8.00
Total	$928.42
Total After Stipend	$487.43

9 CONCLUSIONS AND RECOMMENDATIONS

Our team is participating in the NASA Johnson Space Center Micro-g NExT design challenge. We pursued a solution to support lunar surface extravehicular activity (EVA) operations by developing a device to dispense sample bags that will hold geological samples. We created a dispenser that is easily operable by astronauts using one hand with limited dexterity to fill sample containers. With the foundation we created utilizing our background knowledge, we developed several potential solutions for this challenge during the ideation process. We developed prototypes and used several methods including analysis through Pugh matrices, morphological matrices, and weighted decision matrices in order to determine a design direction. After receiving feedback, we decided to modify our design to add several features to improve ease-of-use. This concept was verified with a structural prototype. With detailed design complete, we developed and executed a manufacturing plan to create the verification prototype which was tested through a multi-step process including inspections and land and underwater testing. Our device has been sent to Johnson Space Center for underwater testing in the NBL on June 15, 2021, and we look forward to the results.

Recommendations

Throughout our project, we identified several opportunities for improvement. Many of these centered around the manufacturing processes, as identified in Section 6.3, Manufacturing Challenges and Lessons Learned. Many team challenges were related to the COVID-19 restrictions, which made certain aspects such as team bonding difficult early in the process. We also were restricted to short time slots in the machine shop due to restrictions, which stretched out the machining process. However, some aspects of the virtual-based learning environment benefitted our team and could be adapted for future senior project experiences, such as the added scheduling flexibility due to asynchronous class periods.

Acknowledgements

We are extremely grateful for the opportunity to have executed a project through its entire design, build and test cycle. Despite the challenges created by the COVID-19 restrictions, it was a challenging, rewarding experience which advanced our critical thinking and hands-on machining skills. We would like to thank our faculty advisor, Dr. Mohammad Noori, for his ongoing support of our project. Thank you to our NASA mentor, Heidi Hammerstein, for providing valuable insight throughout all phases of our project. We also thank the Micro-g NExT Staff and technical partners including Mary Walker for providing this challenge, stipends, and giving valuable feedback on our design deliverables. Finally, we thank Cal Poly ME Senior Project for providing funding.

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APPENDIX A: QFD HOUSE OF QUALITY

Correlations	
Positive	+
Negative	–
No Correlation	

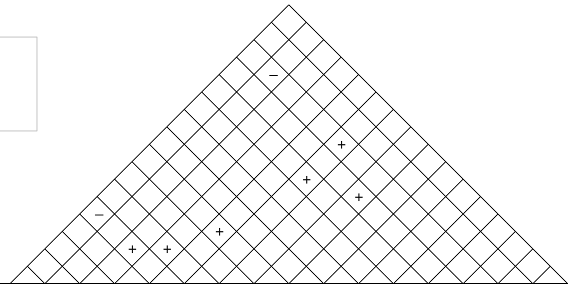
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: F26 NASA Sample Container Dispenser

Revision Date: 10/6/20

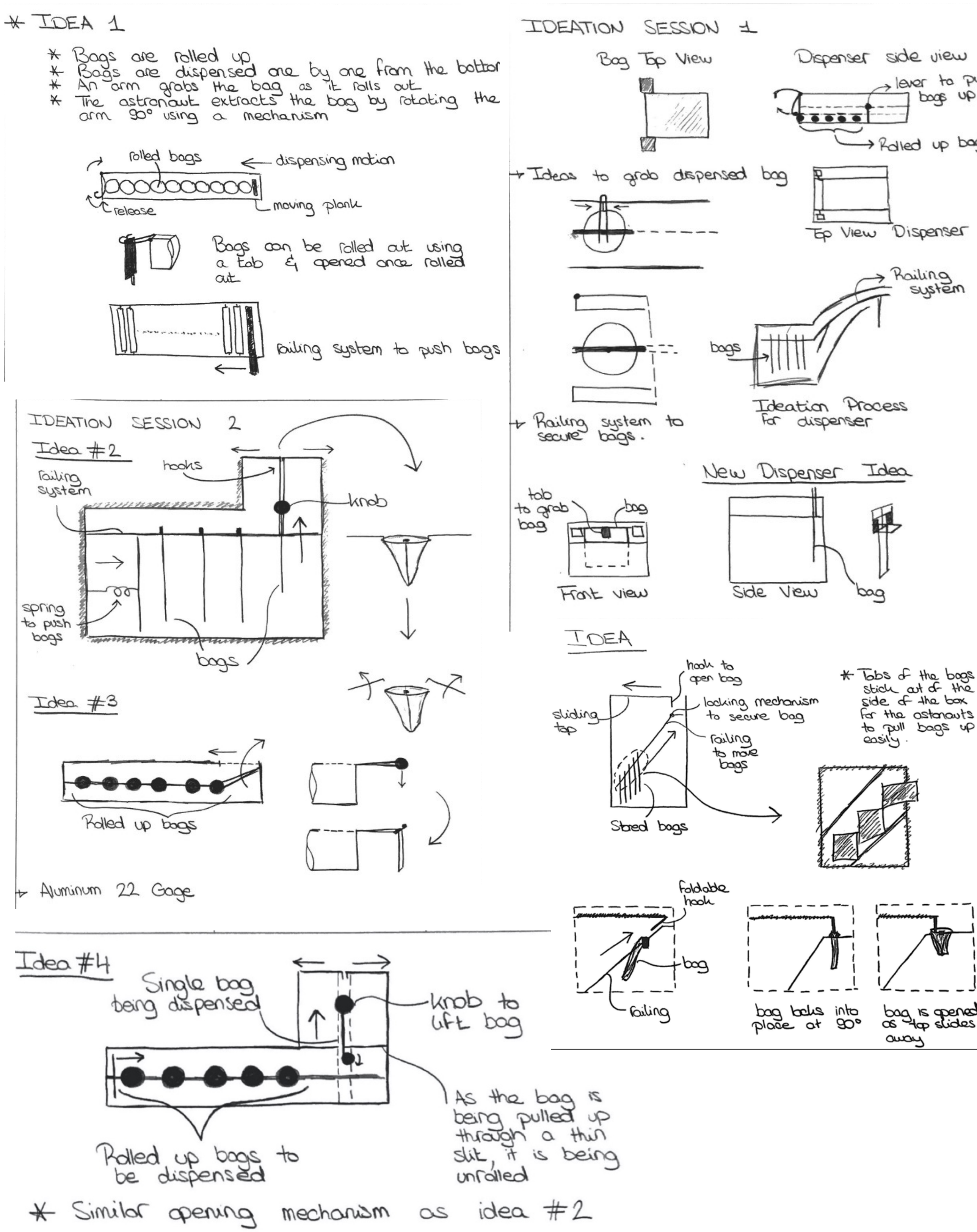


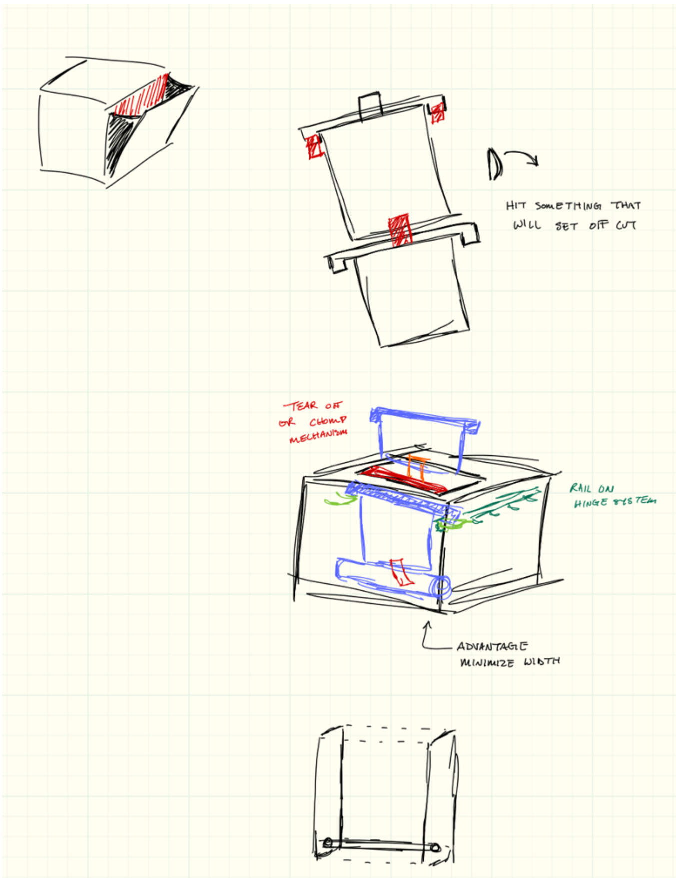
WHO: Customers | NOW: Curr. Products

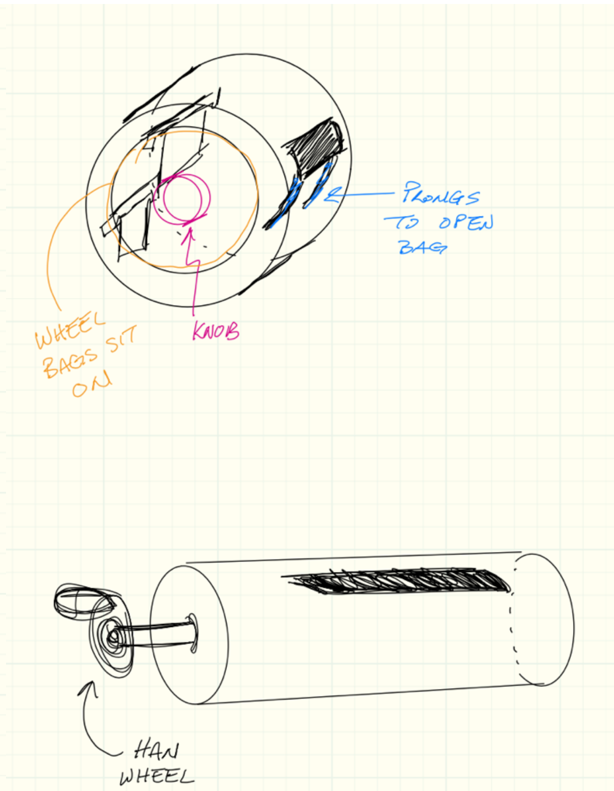
Row #	Weight Chart	Relative Weight	NASA Micro-g NExT	Astronauts			Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) \ HOW: Engineering Specifications (Tests)	Qty Bags (#)	Sample Weight Held (lbs)	Dimensions (inches)	Mode of Operation	Total Weight (lbs)	Ease of Operation Study	Interface Pattern Within Tolera	Material Selection Comparison	Sharp Edge Evaluation	Identify Pinch Points	Dispense one bag at a time	One-handed Operation Test	Damage Test	Bag Remains Attached Use Cas			Apollo Doc. Sample Bag Dispen	Apollo Cup-Shaped Bag Dispens	Grocery bag dispenser	Bag Dispenser Patent US76248		Row #
								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
								Direction of Improvement	◇	◇	▼	◇	▼	▲	◇	◇	▼	▼	◇	▲	▲	◇								
1		7%	10	5			9	Hold 20 Sample Bags	●													○			5	0	0	0		1
2		9%	9	10			9	Open bags w/ one hand						●						●					1	4	5	1		2
3		7%	8	7			9	Protect bags when not in use			▽						▽				●				3	3	2	5		3
4		8%	7	10			9	Ease of use						○					●						2	3	4	1		4
5		7%	9	7			9	Hold up to 3 lbs of sample		●									○			●			2	5	5	5		5
6		6%	8	6			9	Manual power only				●													5	5	5	5		6
7		5%	10	2			9	Max Volume 12"x12"x5" Volume			●		▽								▽				5	0	1	4		7
8		5%	10	2			9	Fit 4-hole bolt pattern interface							●										0	0	0	0		8
9		8%	7	10			9	Operable with EVA gloved hands						●						○					4	5	1	0		9
10		5%	8	4			9	Total weight less than 2 lbs			▽		●												5	5	3	3		10
11		7%	7	8			9	Prevent entrapment of fingers										●							5	3	3	4		11
12		6%	10	3			9	Aluminum, Stainless Steel or Teflon								●									5	5	3	2		12
13		6%	7	6			9	No sharp edges									●				▽				5	5	5	5		13
14		5%	7	5			9	Minimize + label pinch points										●		▽					5	5	3	1		14
15		8%	8	9			9	Simple and Reliable				○		●											4	4	4	3		15
16		0%																												16

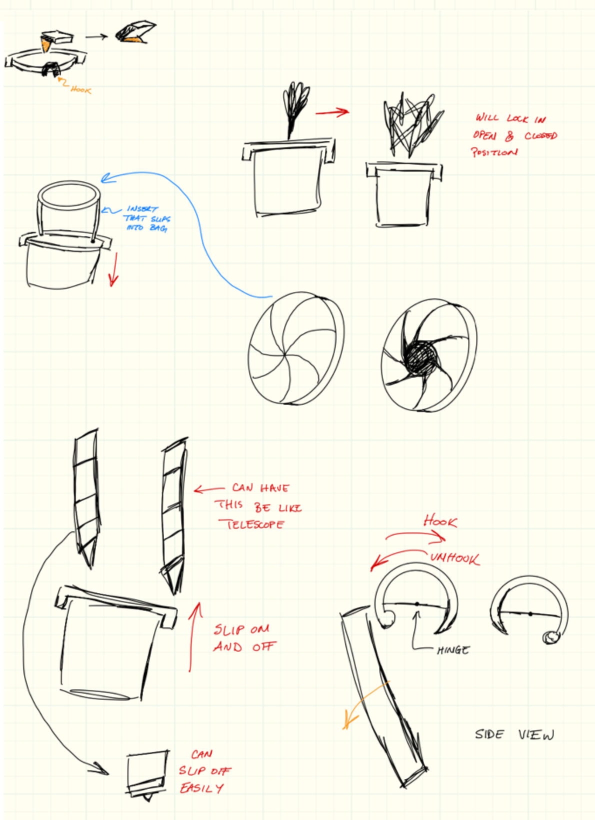
HOW MUCH: Target Values	20 Sample Bags	3 lbs sample	12"x12"x5"	Manual Power Only	Max. weight 2 lbs	Operable with glove	4-hole bolt pattern spec	Aluminum, Stainless Steel, or Teflon	All edges filleted	Check for pinch points and labels	One bag at a time	Full operation with one hand	Undergo damage + contam. tests	Open bag remains in dispenser		
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9		
Technical Importance Rating	59.94	65.91	57.83	81.49	53.01	249.6	45.57	50.36	60.85	112.6	95.04	110.1	73.37	85.89	0	0
Relative Weight	5%	5%	5%	7%	4%	21%	4%	4%	5%	9%	8%	9%	6%	7%	0%	0%
Curr. Products: Apollo Doc. Sample Bag Dispenser	5	1	4	5	5	3	0	5	5	5	2	0	4	0		
Apollo Cup-Shaped Bag Dispenser	0	3	5	5	5	4	0	5	5	4	5	4	4	5		
Grocery bag dispenser	0	0	4	5	0	0	0	3	3	1	4	3	1	5		
Bag Dispenser Patent US7624881B2	0	1	5	5	3	1	0	0	2	1	4	0	1	5		
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

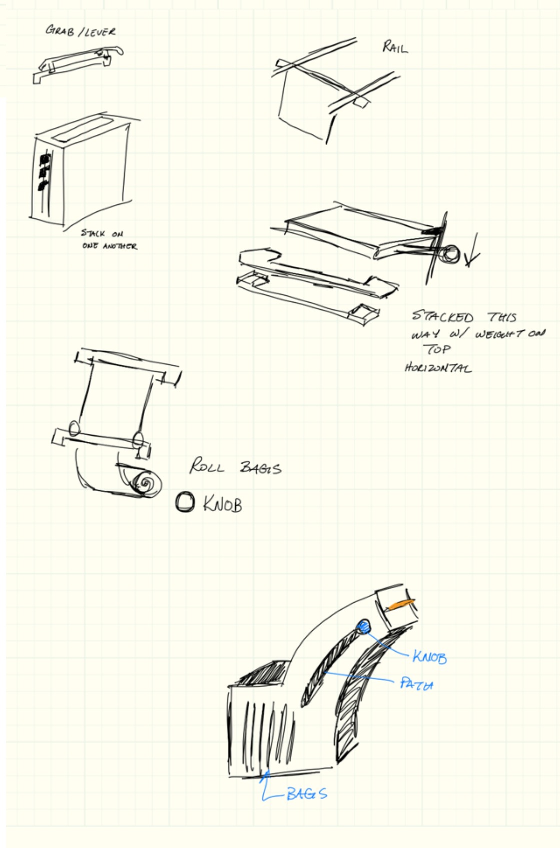
APPENDIX B: IDEATION LIST



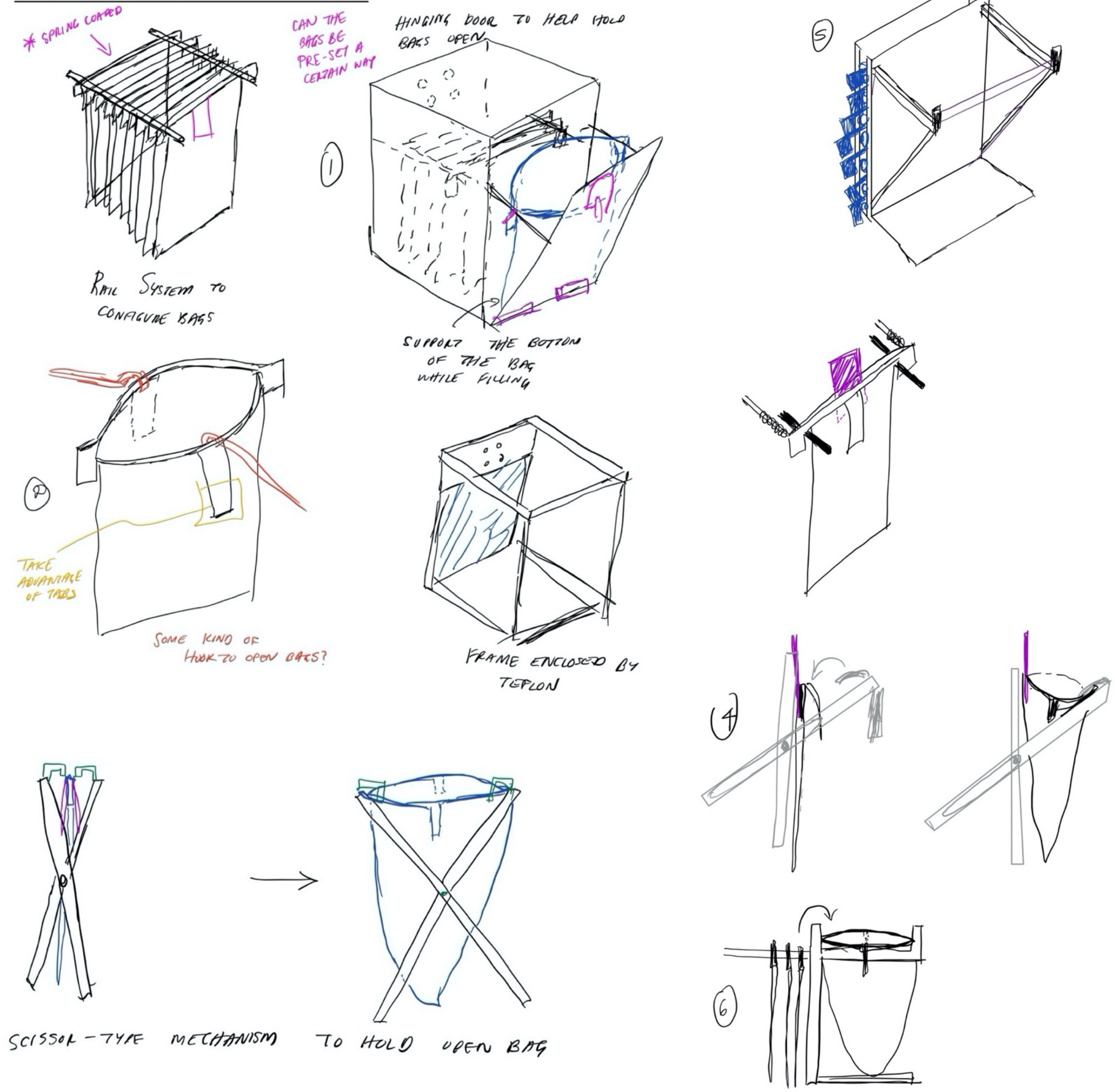

HIT SOMETHING THAT WILL SET OFF CUT
TEAR OFF OR CHOMP MECHANISM
RAIL ON HINGE SYSTEM
ADVANTAGE MINIMIZE WIDTH

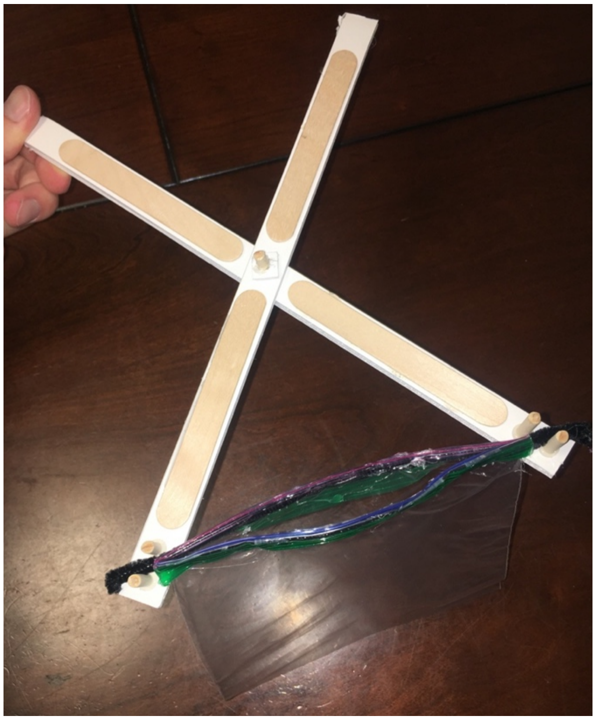

PRONGS TO OPEN BAG
WHEEL BAGS SIT ON
KNOB
HAN WHEEL

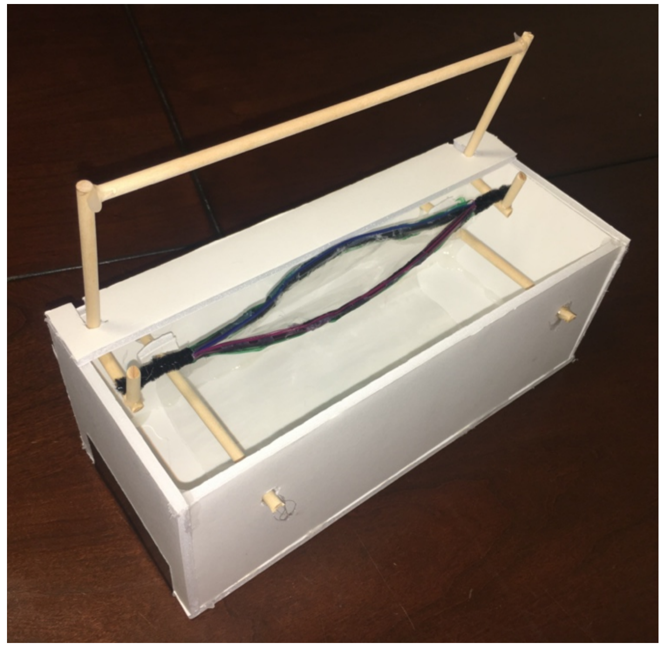

INSERT THAT SLIPS INTO BAG
WILL LOCK IN OPEN & CLOSED POSITION
CAN HAVE THIS BE LIKE TELESCOPE
HOOK
UNHOOK
SLIP ON AND OFF
HINGE
SIDE VIEW
CAN SLIP OFF EASILY

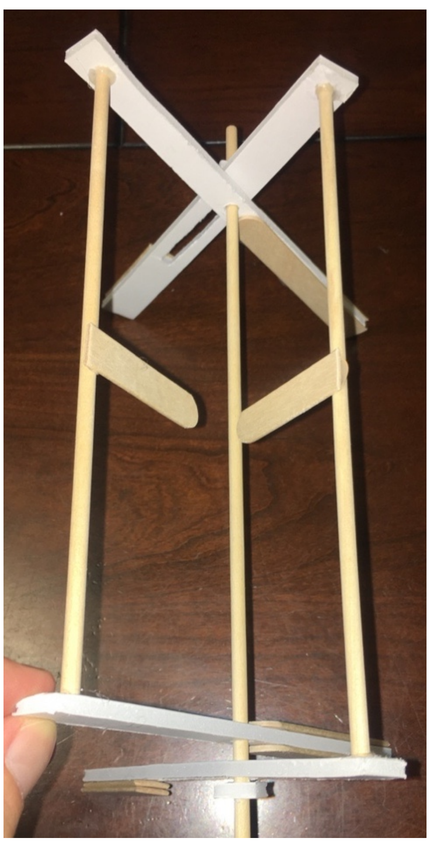

GRAB / LEVER
RAIL
STACK ON ONE ANOTHER
STACKED THIS WAY W/ WEIGHT ON TOP
HORIZONTAL
ROLL BAGS
KNOB
KNOB
PATH
BAGS

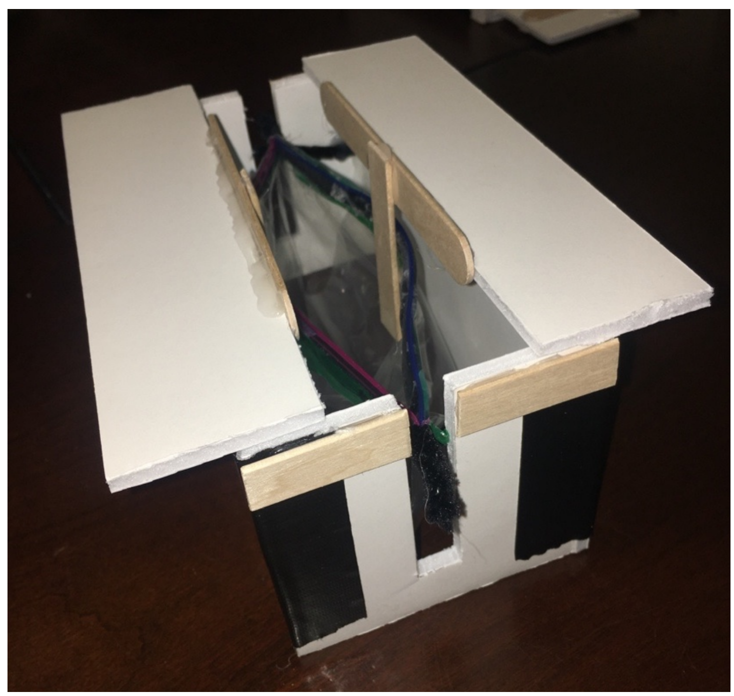
FUNCTION: DISPENSE SAMPLE BAGS (GENERAL)

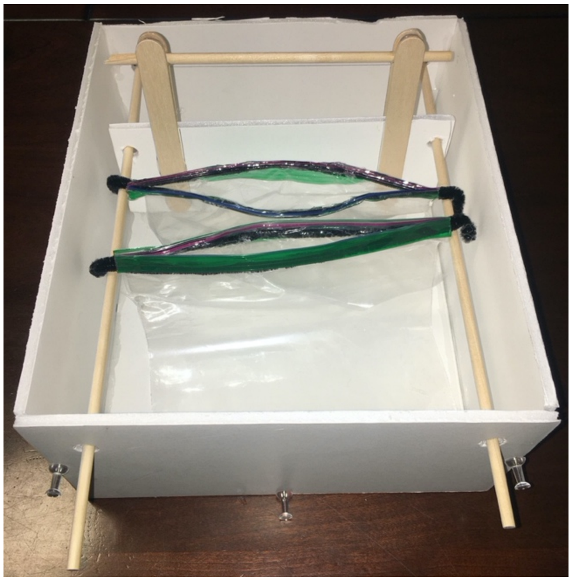


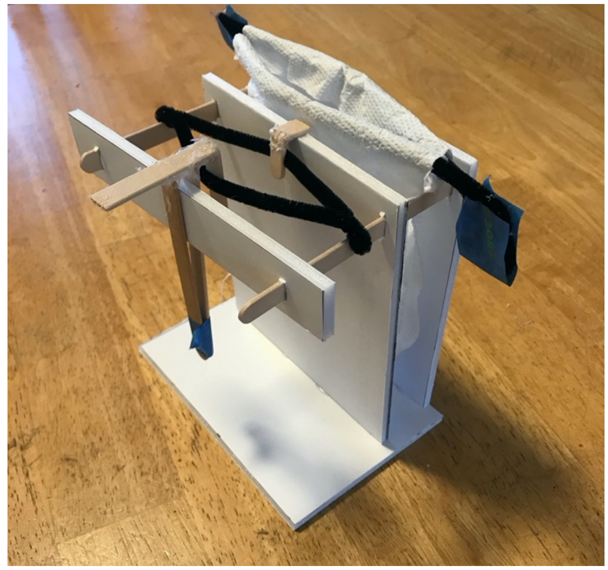


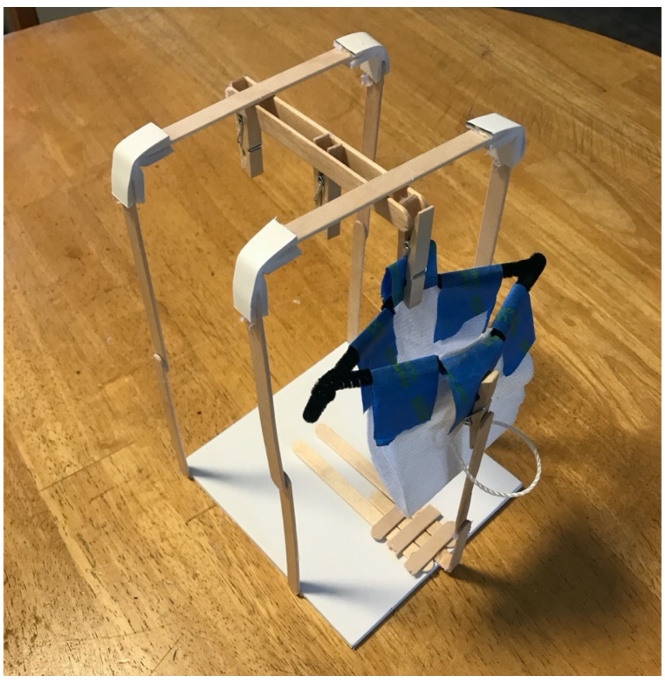


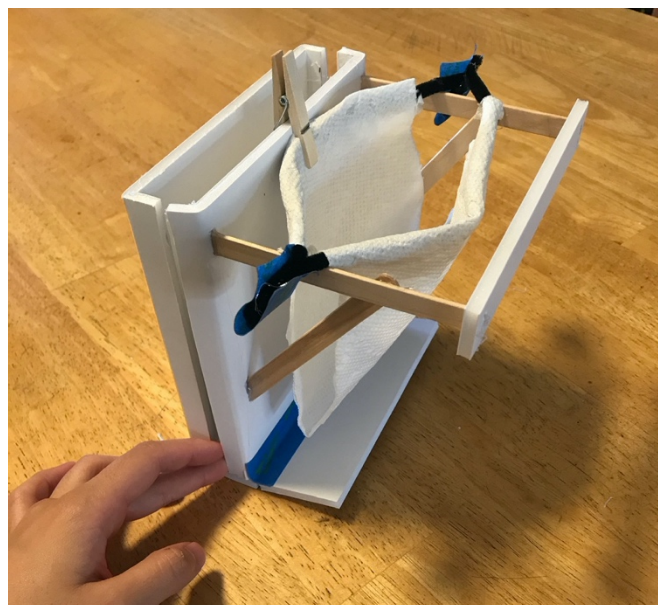












APPENDIX C: DECISION MATRICES

Table 10. Morphological Matrix.

Required Functions	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5	Idea 6	Idea 7	Idea 8	Idea 9
Contain Sample Bags (Multiple)	Bags on rails	Rolled & stacked bags	Rail with tabs clipped	Rolled in series	Bags on a wheel				
Secure bags	Double rail/sandwiched	Bag "compartment"	Held by clamps	Wall separator					
Configure bags	By hand	Hook	Rolled	Clamp	Line up	Preloaded configuration			
Open bag with one hand / stay open	Bag slides onto insert	Insert placed into bag	Clamp-Hook holds bag while fold open	Scissor compression opener	2-DOF rotational opener	Sliding hooks	Scissor expansion opener	Pull tab opening	2-DOF Sliding Hook
Dispense one bag at a time	One-way flap	Pulling on tabs/manual	Connected by perforated tabs	Vertical Slider	Wheel - slot				
Protect sample bags from damage	Bag compartment	Wall to separate							
Prevent contamination/keep bags closed before use	Bag compartment	wall to separate	Rolled bags						
Attach to carrier	Bolt pattern								
Use with spacesuit gloves	Handles for mechanism	Tabs exposed	Insert	Knobs					

Table 11. Pugh Matrices.

FUNCTION 1: CONTAINING / PROTECTING BAGS

CONCEPT / CRITERIA	DATUM APOLLO-ERA HOLDER	1 BAGS ON RAILS	2 ROLLED + STACKED BAG	3 TABS HELD W/ CLIPS	4 BAGS ROLLED IN SERIES	5 BAGS ON A WHEEL
WEIGHT		–	–	–	S	–
SIZE		–	–	–	S	–
COST		–	–	–	S	–
MANUFACTURABILITY		S	–	–	–	–
SIMPLICITY/ RELIABILITY		S	S	–	+	–
EASE OF USE		S	S	–	S	–
EXECUTION OF FUNCTION		+	+	S	S	–
TOTAL	0	–2	–3	–6	0	–7

FUNCTION 2: OPENING BAGS / STAYING OPEN

CONCEPT / CRITERIA	DATUM APOLLO-ERA HOLDER	1 SCISSOR EXPANSION	2 PULL TAB OPENER	3 SCISSOR COMPRESSION	4 2DOF ROTATIONAL OPENER	5 2DOF SLIDING HOOK
WEIGHT		–	–	–	–	–
SIZE		–	–	–	–	–
COST		S	–	S	–	–
MANUFACTURABILITY		S	–	S	–	–
SIMPLICITY/ RELIABILITY		S	–	+	+	+
EASE OF USE		–	–	S	+	+
EXECUTION OF FUNCTION		+	+	+	+	+
TOTAL	0	–2	–5	0	–1	–1

FUNCTION 3: DISPENSE 1 BAG AT A TIME

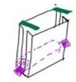
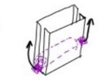
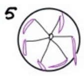
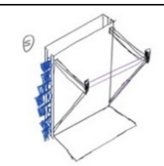
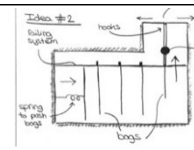
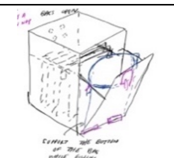
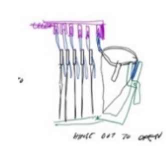
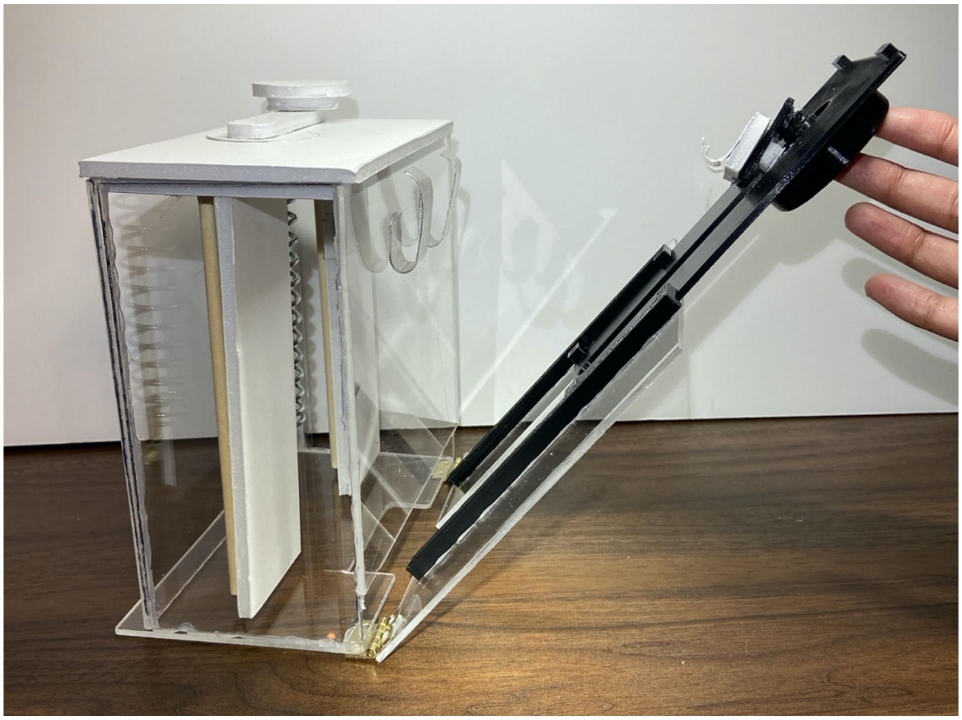
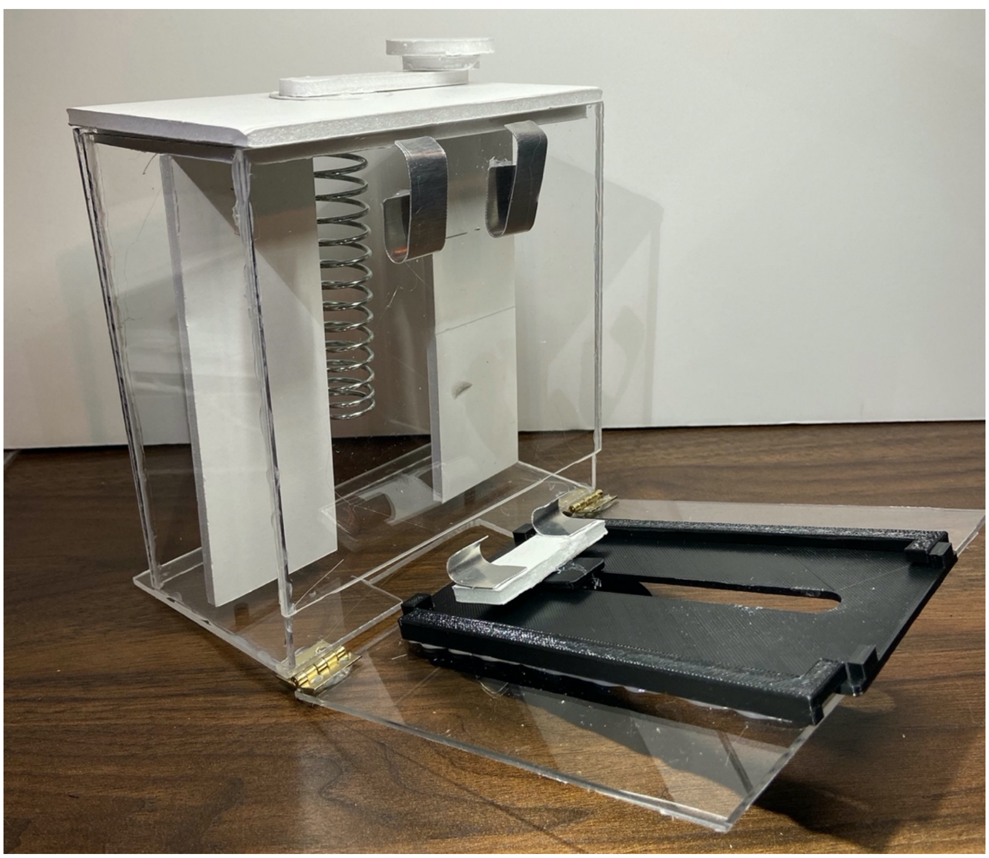
CONCEPT / CRITERIA	DATUM APOLLO-ERA HOLDER 	1 ONE-WAY FLAP 	2 GRAB ALUMINUM TABS 	3 VERTICAL SLIDER 	4 BREAK PERFORATED TAPE 	5 THROUGH A SLOT 
WEIGHT		S	S	S	S	S
SIZE		S	S	–	S	–
COST		S	S	S	S	S
MANUFACTURABILITY		S	S	–	–	–
SIMPLICITY/ RELIABILITY		S	S	–	S	–
EASE OF USE		+	+	S	–	S
EXECUTION OF FUNCTION		+	+	S	S	–
TOTAL	0	+2	+2	–3	–2	–4

Table 12. Weighted Decision Matrix.

Criteria	Weight				
Holds 20 Sample Bags	0.05	5	5	5	5
Holds 2 lbs sample	0.05	3	3	4	2
Fits Stowed Volume	0.1	5	2	4	2
Simplicity	0.05	4	2	3	1
Total Weight <3lbs	0.1	5	2	3	2
Dispenses One Bag at a Time	0.2	5	5	5	4
Ease of Operation w/ One Hand	0.3	4	3	3	4
Withstands Damage	0.05	3	4	4	3
Bag Remains Attached	0.1	5	4	5	4
Total	1	4.45	3.4	3.9	3.35

APPENDIX D: STRUCTURAL PROTOTYPE





APPENDIX E: INDENTED BILL OF MATERIALS (IBOM)

Indented Bill of Material (BOM)

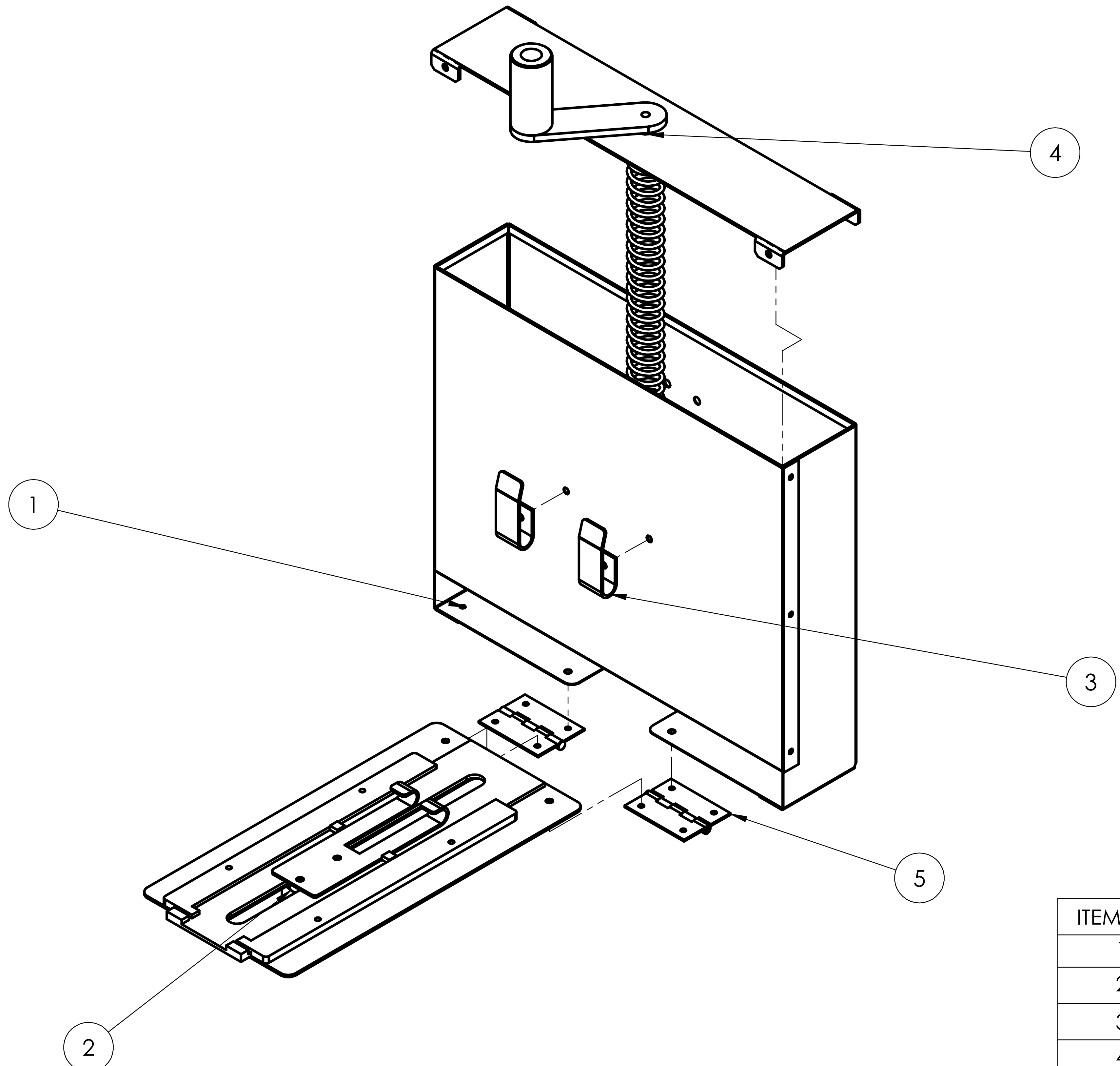
F26 Sample Container Device Assembly

Assy Level	Part Number	Description (Lvl0 / Lvl1 / Lvl2 / Lvl3)	Matl	Vendor	Qty	Cost	Ttl Cost	Description	Vendor RM PN
0	0000	Sample Container Dispensing Device							
1	0100	Bag Container							
2	0110	Container Walls	Al 6061-T6	McMaster-Carr	2	$32.36	$ 64.72	Al-6061 Sheet 0.025" Thickness 24"x48"	89015K143
2	0120	Bag Inner Walls	Al 6061-T6	McMaster-Carr	1			Same as above	
2	0130	Coil	High Carbon	Grainger	1	$11.12	$ 11.12	Compress Spring Stock 12 in L	1NBX7
2	0140	Hooks	Al 6061-T6	McMaster-Carr	1	$1.42	$ 1.42	1/8" thick bar, 1"x1'	8975K578
2	0150	Crank							
3	0151	Coil holder	Al 6061-T6	Grainger	1	$ 11.65	$ 11.65	1" dia x 3"	2EYG9
3	0152	Arm	Al 6061-T6	Grainger	1	$8.21	$ 8.21	0.125"x1.5"x6"	2EYV8
3	0153	Handle	Al 6061-T6	Grainger	1			Leftover stock from #0151	
2	0160	Lid	Al 6061-T6	Grainger	1	$ 23.20	$ 23.20	Flat bar stock 0.125"x3"x36"	2EYW3
2	0170	Guide Rod	Al 6061-T6	Grainger	1	$ 1.52	$ 1.52	1/4" Dia 6061--T6 Al. Rod Stock x 1ft	48KU31
1	0200	Door							
2	0210	Door Panel	Al 6061-T6	Grainger	4	$7.65	$ 30.60	Aluminum 6061 Sheet 0.064" Thickness 6"x12"	15V219
2	0220	Door Sliding Panel	Al 6061-T6	Grainger	1	$ 14.23	$ 14.23	Flat bar stock 0.187" thickness, 3"x36"	2EYW7
2	0230	Slider Guides	Al 6061-T6	Grainger	1	$ 8.42	$ 8.42	Flat bar stock 0.187" Thickness, 2"x36"	2EYW5
2	0240	Door Lock	Al 6061-T6	McMaster-Carr	1	$ 7.53	$ 7.53	Extra Sheet from Bag Container	
2	0250	Door Hinge	SSTL	Grainger	6	$ 5.09	$ 30.54	1.5"x2.25" Butt Hinge	3HTT8
2	0260	Hooks	Al 6061-T6	McMaster-Carr				Same as hooks above	
2	0270	Knob	Al 6061-T6	McMaster-Carr	2	$ 6.32	$ 12.64	2"x1" aluminum round	1610T15
2	0280	Sliding Hook Panel	Al 6061-T6	McMaster-Carr				Unused flat bar stock from above	
2	0290	Knob Spacers	Al 6061-T6	McMaster-Carr	2	$ 0.70	$ 1.40	Aluminum, 3/8" OD, 1/2" Long, 6-32 Thread Size	93330A591
2	0299	Screws	Al 6061-T6	McMaster-Carr	1 (10)	$ 13.33	$ 13.33	18-8 Stainless Steel Socket Head Screw 6-32, 3/4" Long	92196A024

Purchased Parts Total: $ 227.20

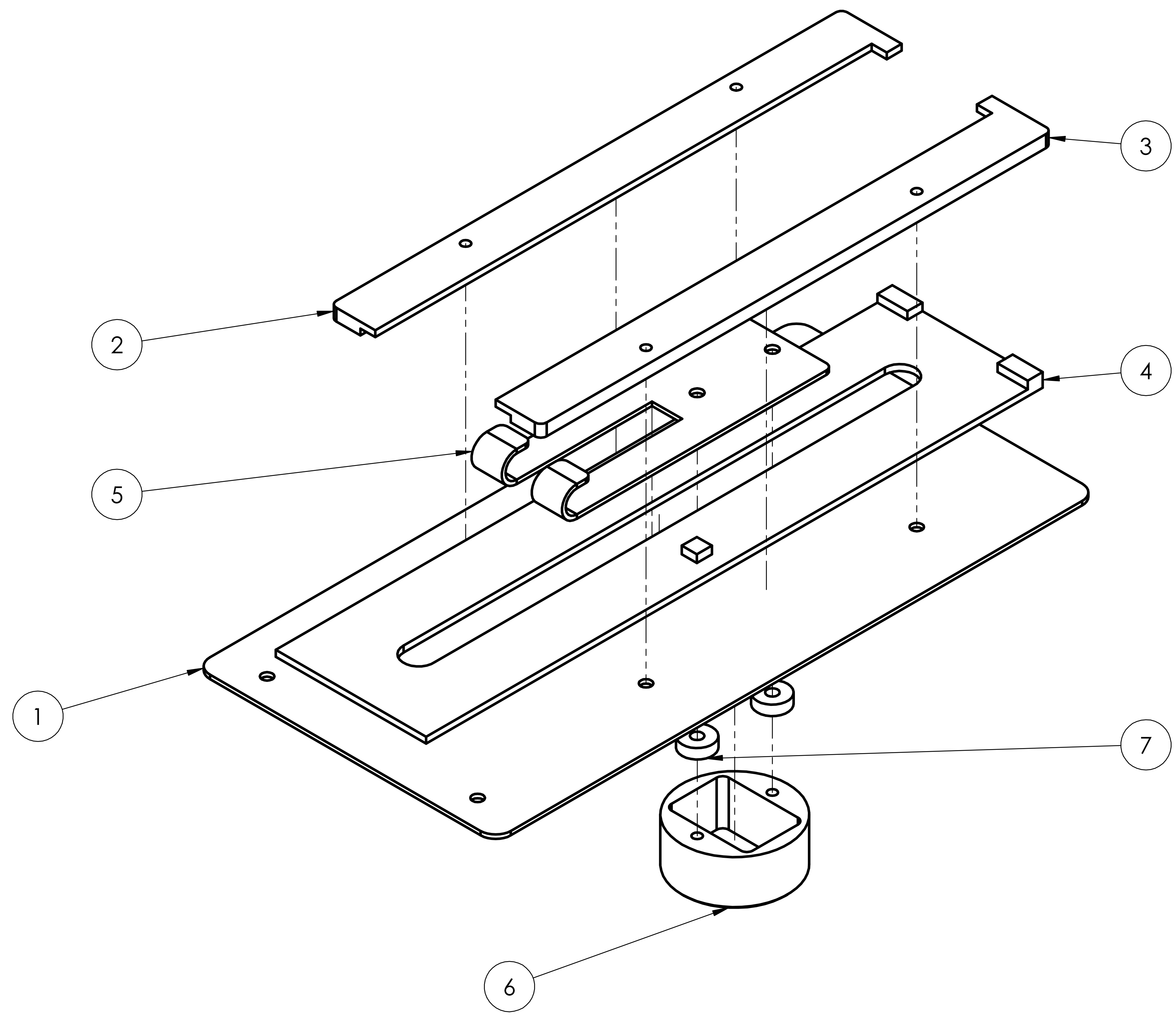
APPENDIX F: DRAWING PACKAGE

See following pages.



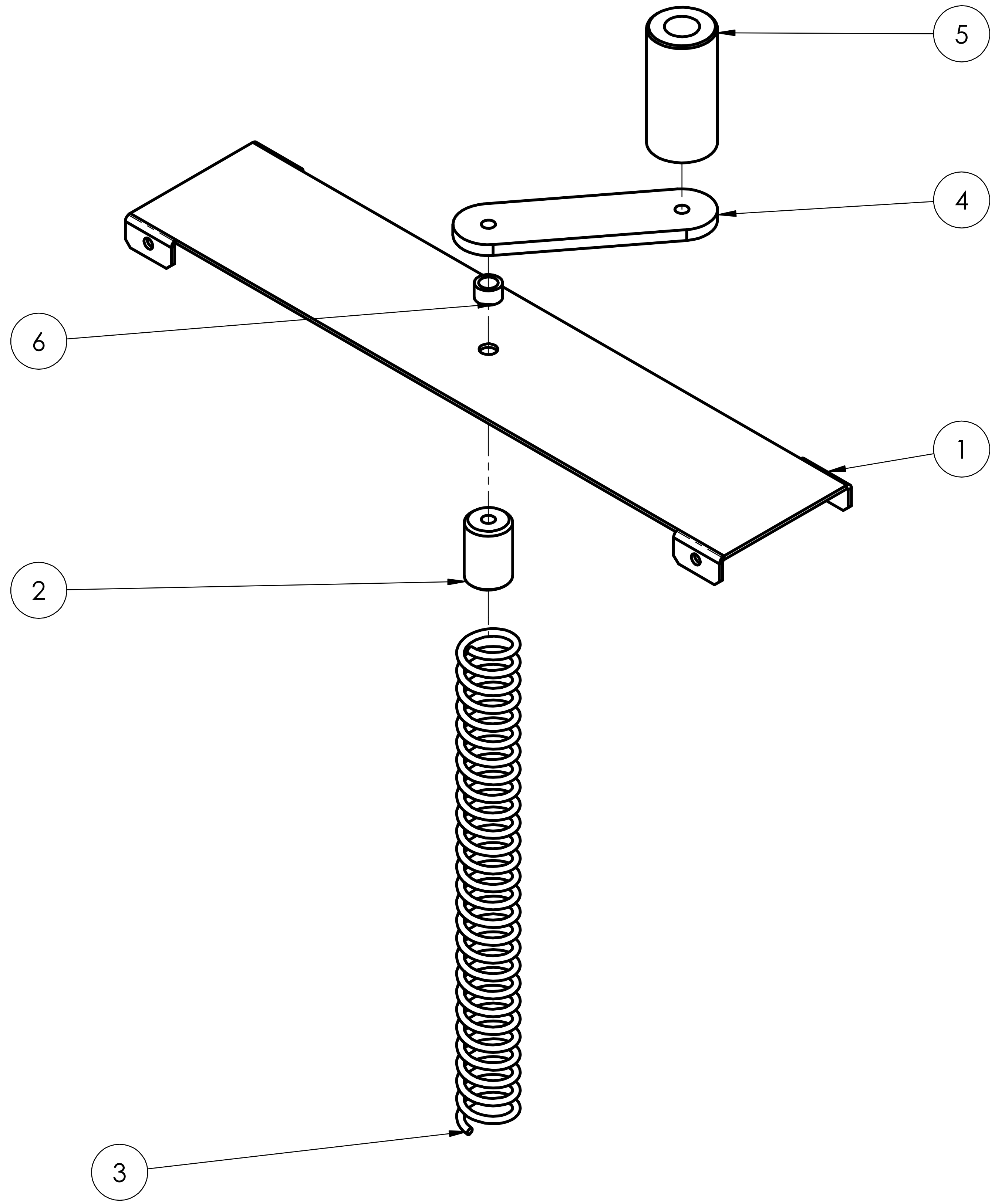
ITEM NO.	PART NUMBER	QTY.
1	Bag Container	1
2	DoorAssembly	1
3	ContainerHook	2
4	CoilAssembly	1
5	Hinge	2

Cal Poly Mechanical Engineering SENIOR PROJECT	Team: MUSTANGS ON THE MOON		Title: HOOK PANEL	Drwn. By: K. KRAYBILL-VOTH
	Dwg. #:	Nxt Asb:	Date: 4/15/21 Scale: 1:1	Chkd. By: O. POPRAVKA



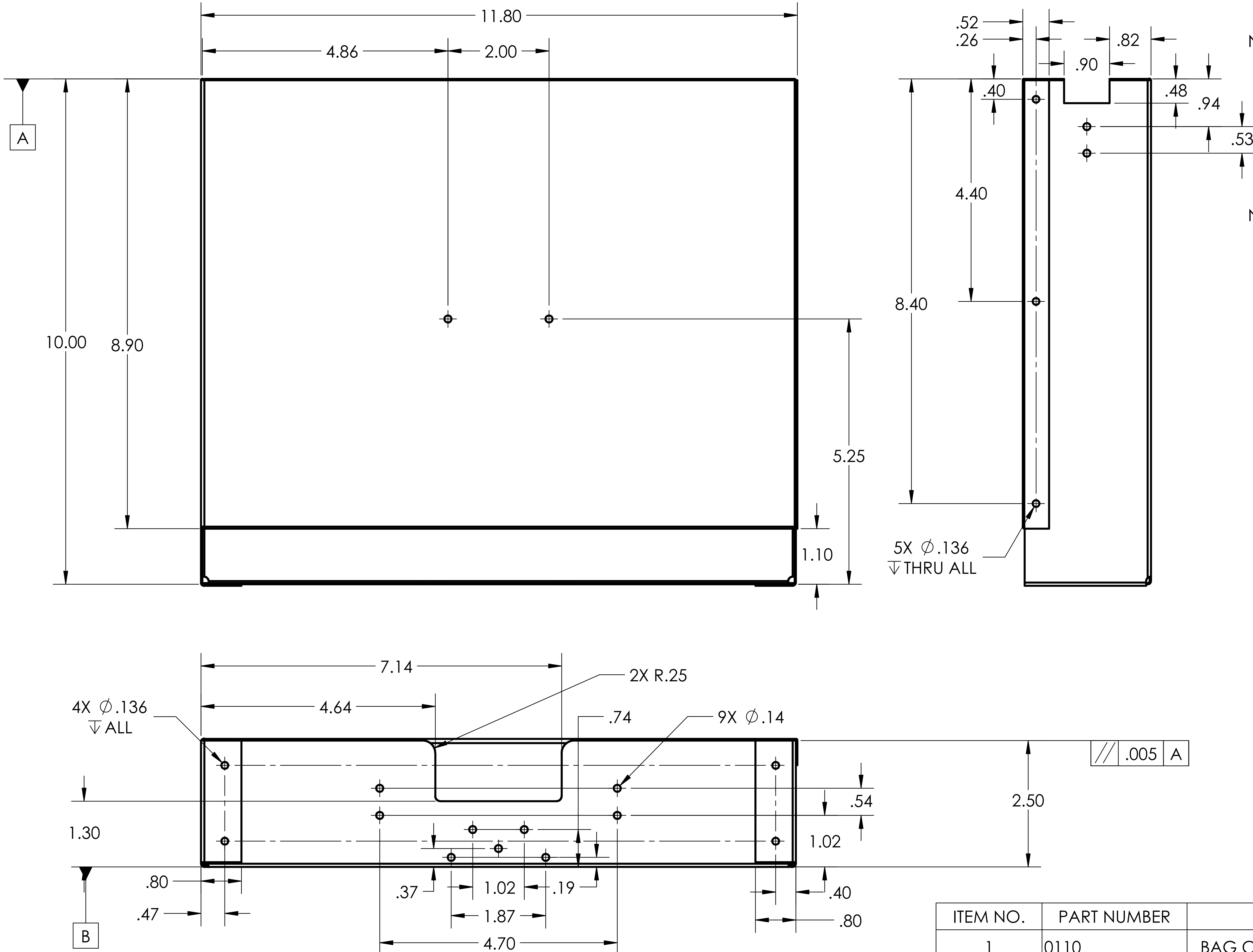
ITEM NO.	PART NUMBER	QTY.
1	DoorPanel	1
2	LeftSliderGuide	1
3	RightSliderGuide	1
4	DoorSlidingPanel	1
5	HookPanel	1
6	DoorKnob	1
7	Spacer	2

Cal Poly Mechanical Engineering SENIOR PROJECT	Team: MUSTANGS ON THE MOON		Title: DOOR ASSEMBLY		Drwn. By: K. KRAYBILL-VOTH
	Dwg. #:	Nxt Asb:	Date: 4/19/21	Scale: 2:3	Chkd. By: O. POPRAVKA



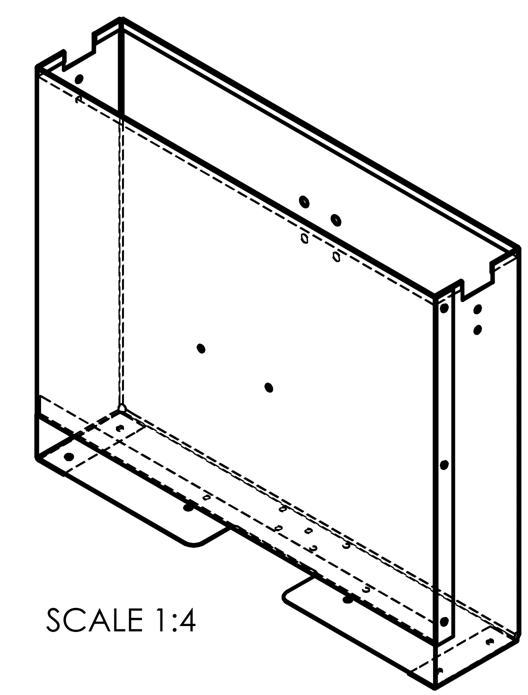
ITEM NO.	PART NUMBER	QTY.
1	Lid	1
2	Coil_Insert	1
3	Coil_Grainger	1
4	CrankArm	1
5	CrankHandle	1
6	crankspacer	1

Cal Poly Mechanical Engineering SENIOR PROJECT	Team: MUSTANGS ON THE MOON	Title: COIL ASSEMBLY	Drwn. By: K. KRAYBILL-VOTH
	Dwg. #: / Nxt Asb:	Date: 4/19/21 / Scale: 1:2	Chkd. By: O. POPRAVKA



NOTES:
- ALL DIMENSIONS IN INCHES
- DRESS CORNERS AND EDGES
- TOLERANCES:
  - X.XX = ±0.01
  - X.XXX = ±.005

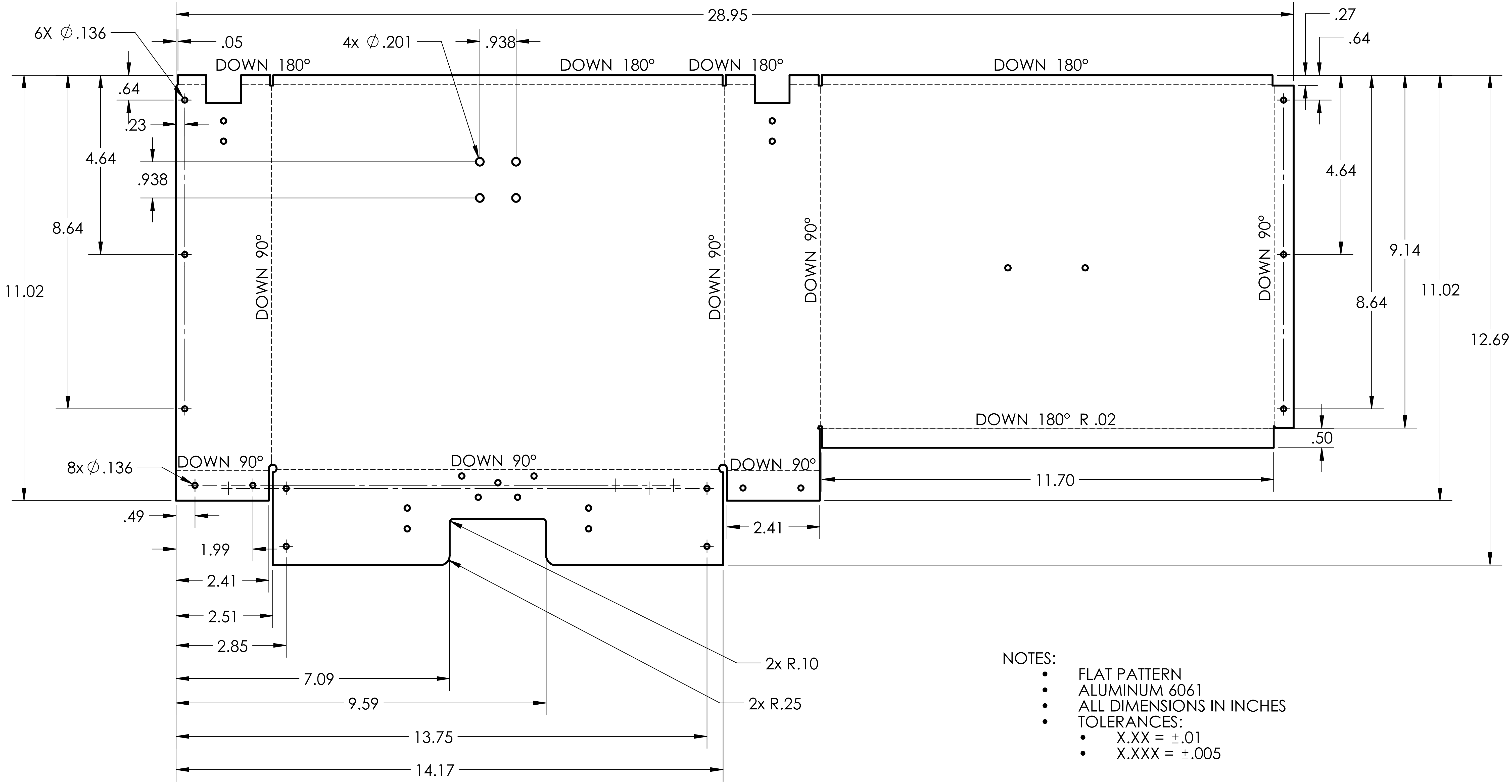
NOTES:
- BENDS MADE AT 90° AND HEMS- TAKE CARE TO AVOID CRACKING WITH AL 6061-T6
- COMPLETE ALL HEMS FIRST (NOTE THE INTERIOR HEMS) THEN BEND



SCALE 1:4

ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL
1	0110	BAG CONTAINER STRUCTURE	AL-6061

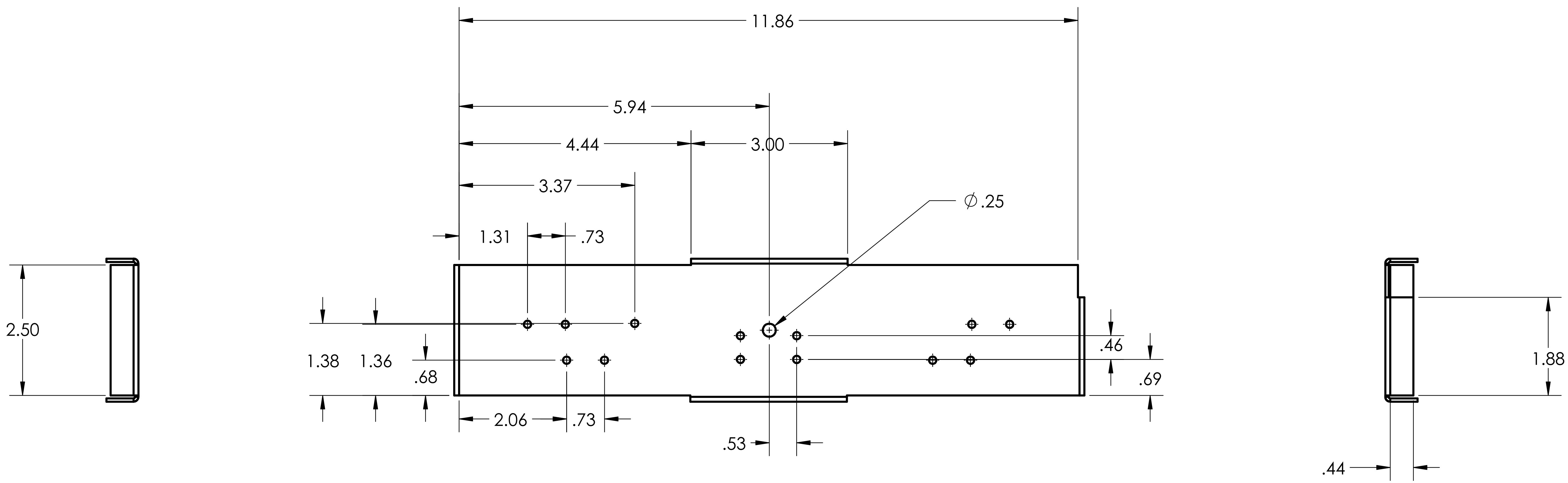
Cal Poly Mechanical Engineering Senior Project	F26		Title: BAG CONTAINER		Drwn. By: K. KRAYBILL-VOTH
	Dwg. #: 0110.1	Nxt Asb:	Date: 5/30/21	Scale: 1:2	Chkd. By: O. POPRAVKA



NOTES:

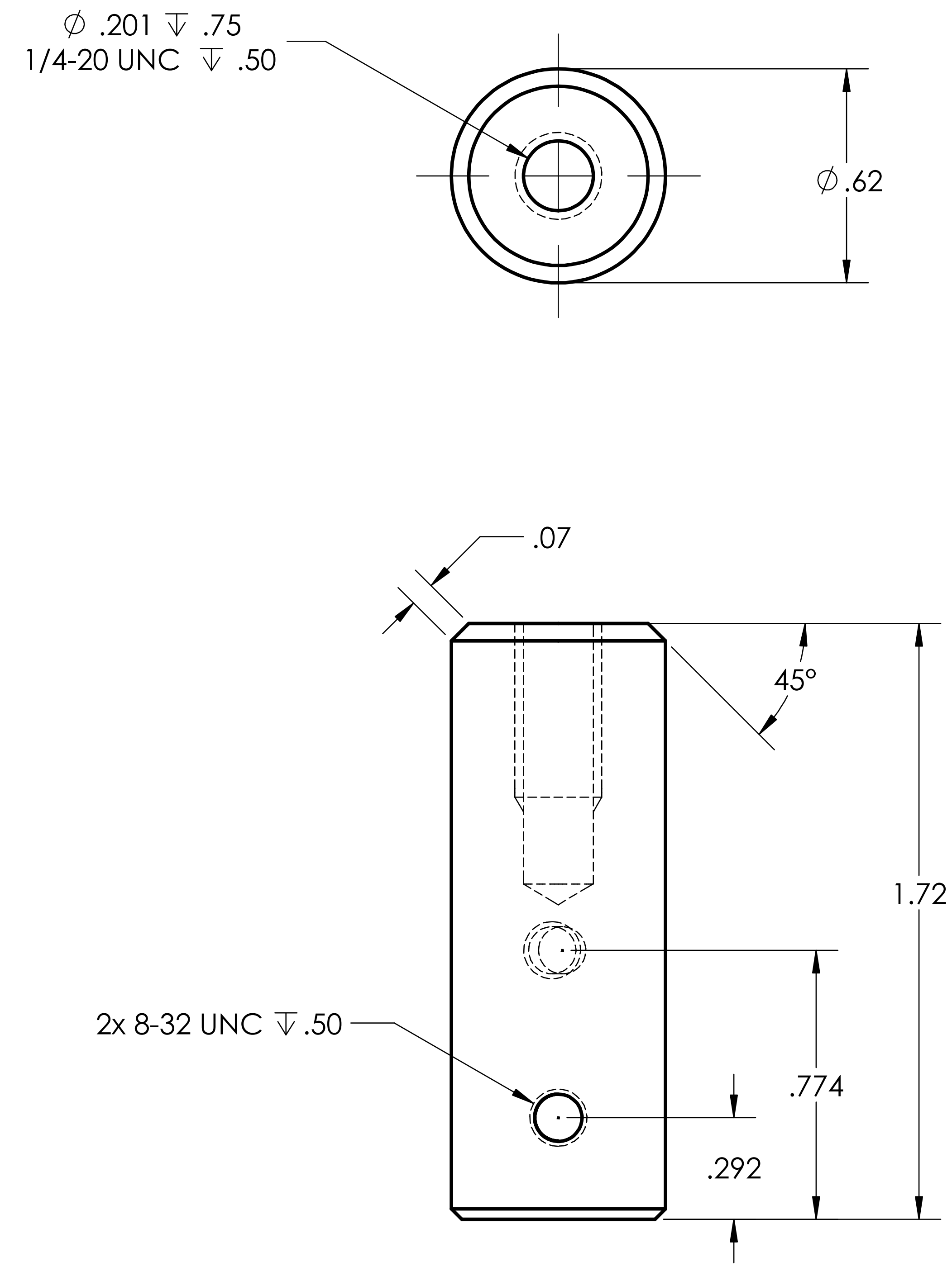
- FLAT PATTERN
- ALUMINUM 6061
- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX = ±.01
  - X.XXX = ±.005

Cal Poly Mechanical Engineering SENIOR PROJECT	F26		Title: BAG CONTAINER		Drwn. By: K. KRAYBILL-VOTH
	Dwg. #: 0110.2	Nxt Asb:	Date: 2/19/21	Scale: 1:2.5	Chkd. By: O. POPRAVKA



NOTES:
- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- TAKE CAUTION ON SHARP BENDS TO 90 DEGREES
- REMOVE SHARP EDGES
- MATERIAL IS 0.050" AL-6061
- HOLE PATTERN SYMMETRIC ABOUT CENTER

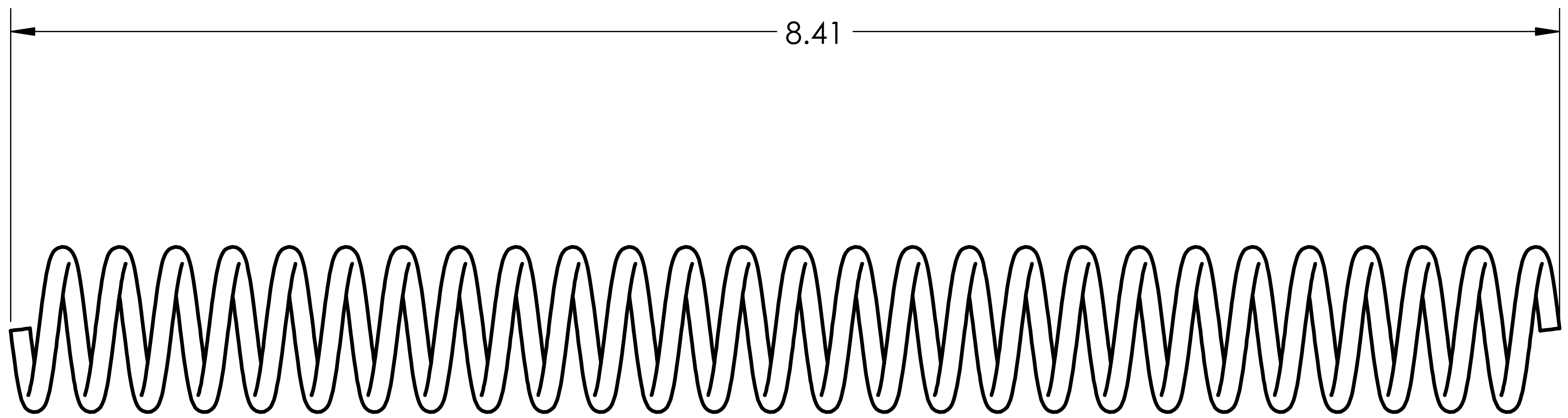
Cal Poly Mechanical Engineering SENIOR PROJECT	Team: MUSTANGS ON THE MOON		Title: LID	Drwn. By: K. KRAYBILL-VOTH
	Dwg. #:	Nxt Asb:	Date: 6/3/21	Scale: 1:2	Chkd. By: O. POPRAVKA

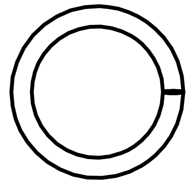


NOTES:

- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- CHAMFER ALL AROUND BOTH EDGES
- ADD SECOND 8-32 UNC HOLE THROUGH TO CENTER, 180 DEGREES AROUND FROM THE HOLE SHOWN.
- ENSURE HOLE IS VERTICALLY OFFSET AS WELL BASED ON THE COIL

Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON		Title: COIL HOLDER	Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #:	Nxt Asb:	Date: 6/3/21 · Scale: 2:1	Chkd. By: O. POPRAVKA





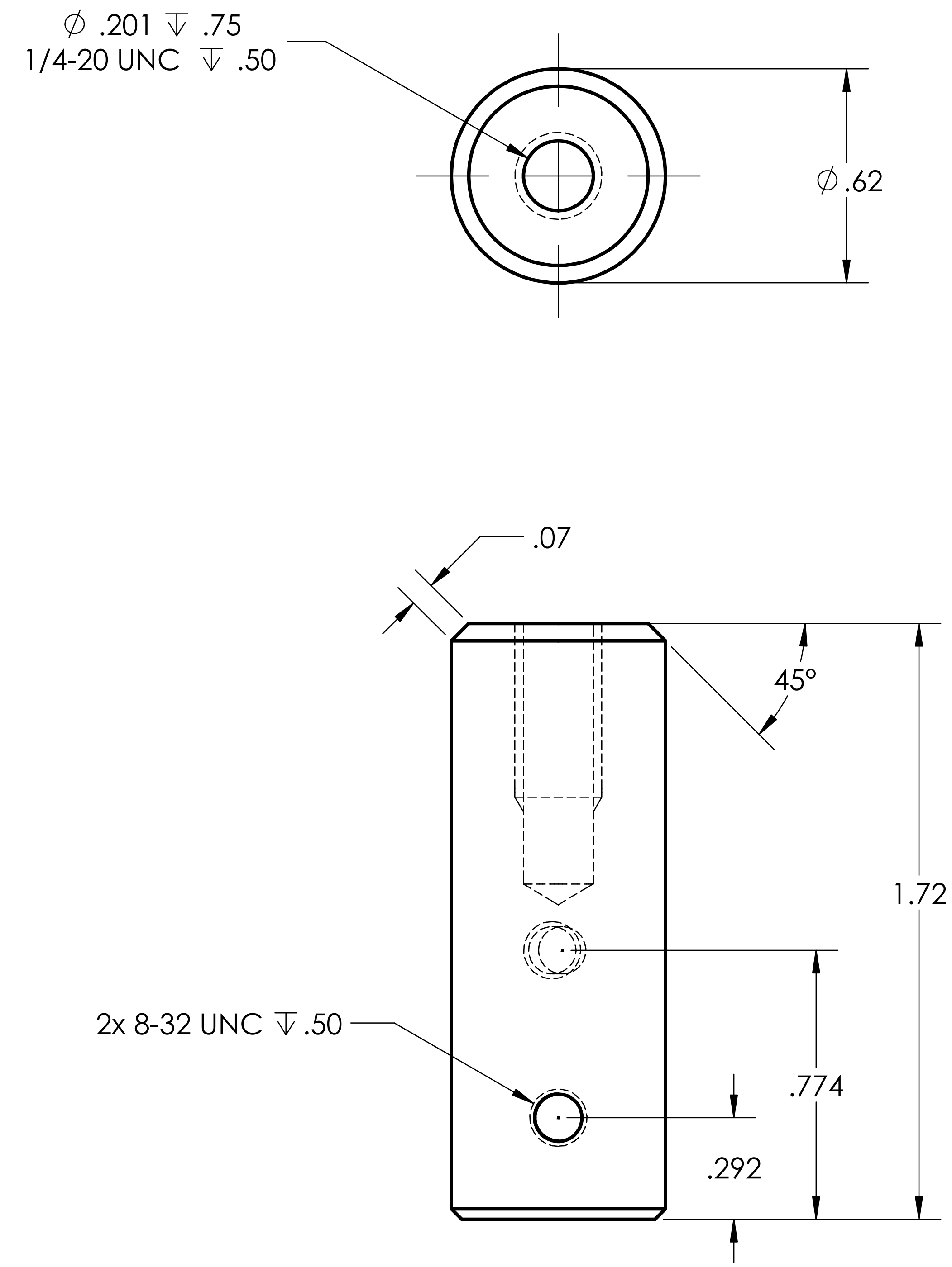
MANUFACTURING NOTES:
1. MEASURE LENGTH OF COIL AND MARK CUT POINT
2. PRIORITY IS ENSURING THERE ARE AT LEAST 20 FREE COILS
3. CLAMP STOCK SECURELY IN A VICE
4. USE AN ANGLE GRINDER TO CUT TO LENGTH
5. USE FILE TO SMOOTH ENDS OF COIL, ENSURING NO BURS REMAIN.

GENERAL NOTES:
- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ±0.1

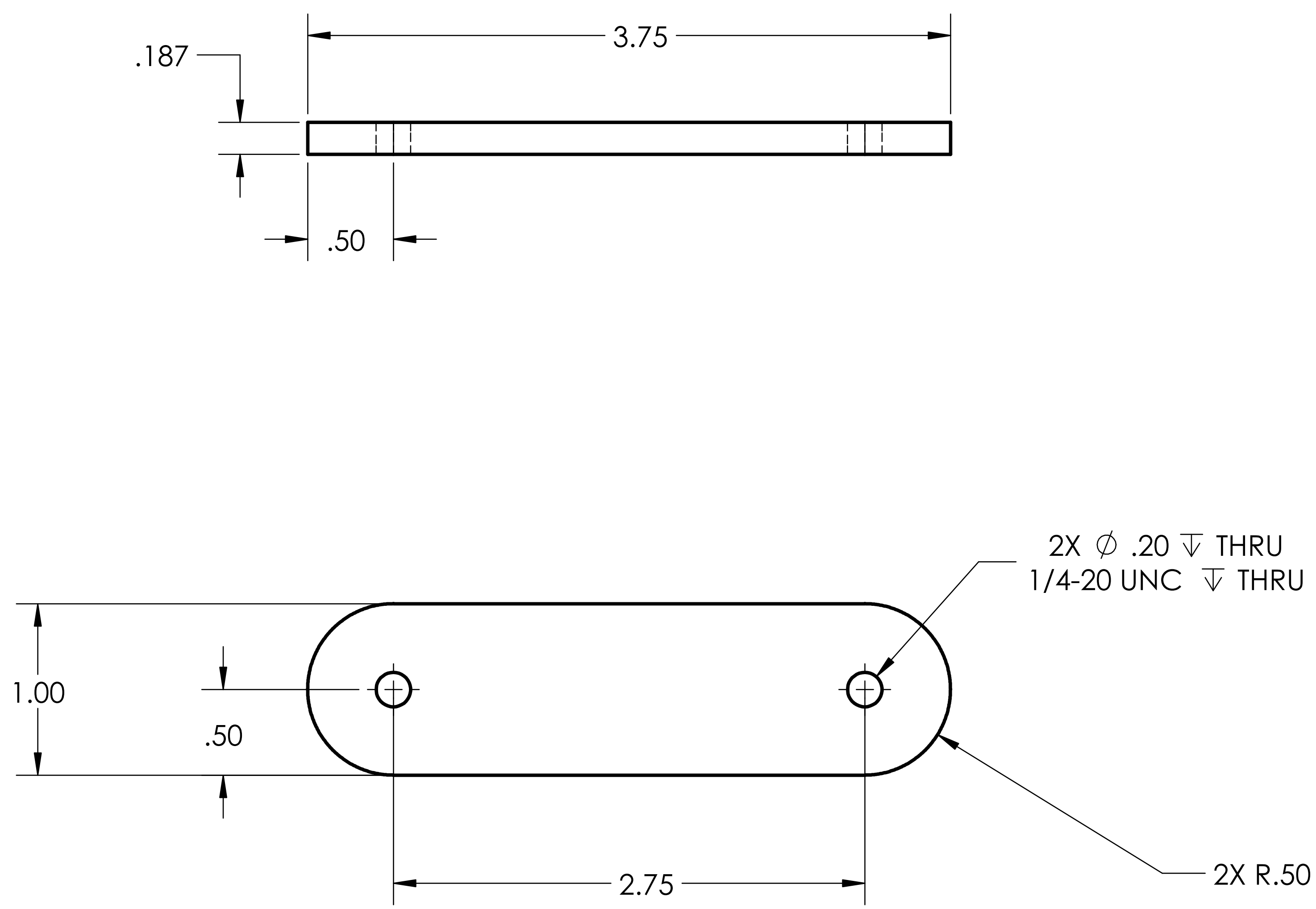
STOCK MATERIAL	OD	WIRE DIA.	COILS PER IN.	SOURCE
HIGH CARBON STEEL	0.844 in.	.106 in.	3.25	GRAINGER

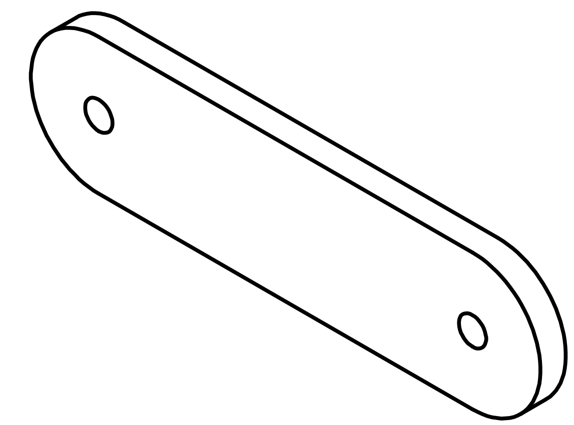
Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON	Title: PROTOTYPE COIL (GRAINGER)	Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #: / Nxt Asb:	Date: 3/11/2021 / Scale: 1:1	Chkd. By: K. MICKELSON

NOTES:
- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- CHAMFER ALL AROUND BOTH EDGES
- ADD SECOND 8-32 UNC HOLE THROUGH TO CENTER, 180 DEGREES AROUND FROM THE HOLE SHOWN.
- ENSURE HOLE IS VERTICALLY OFFSET AS WELL BASED ON THE COIL



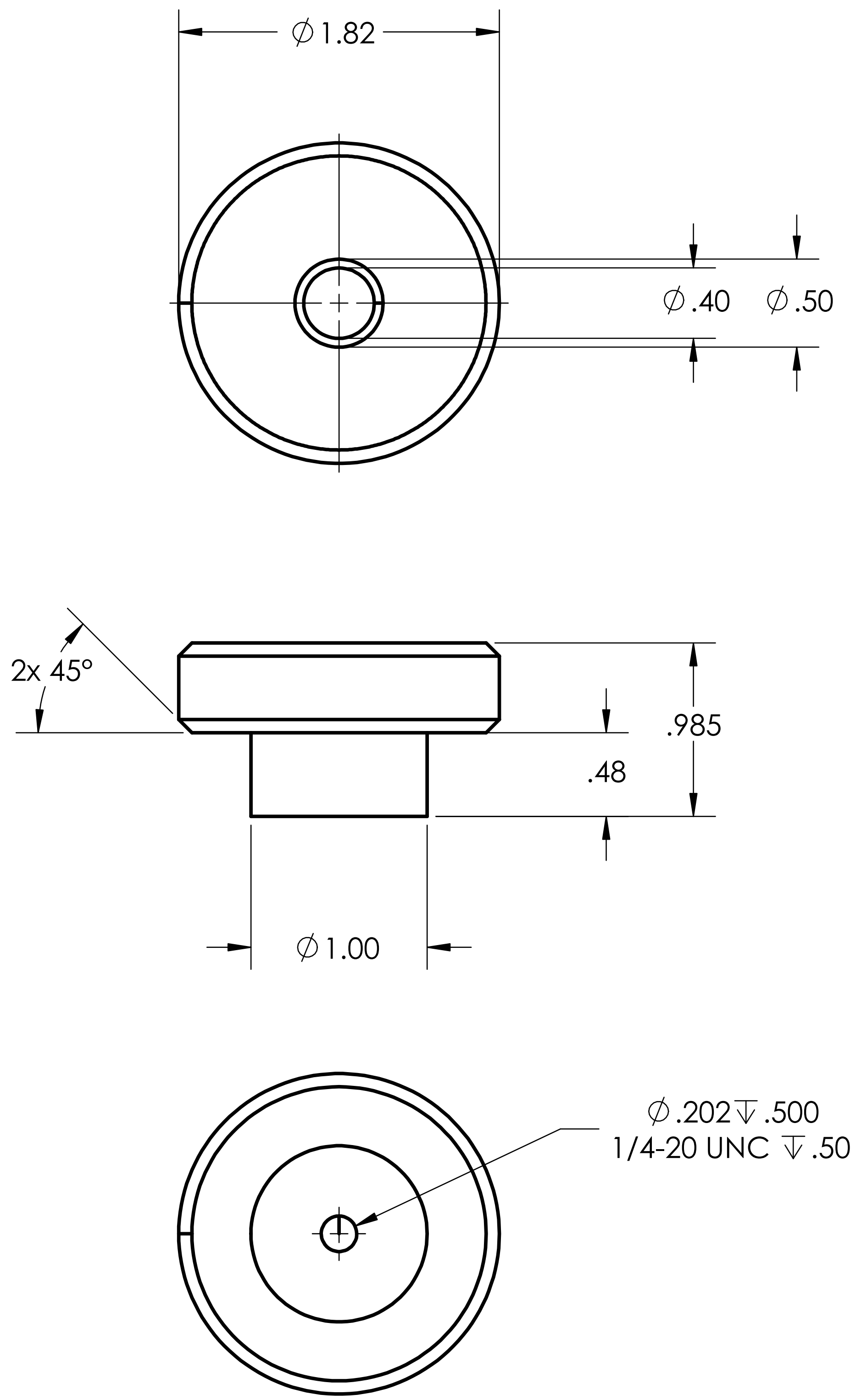
Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON		Title: COIL HOLDER		Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #:	Nxt Asb:	Date: 6/3/21	Scale: 2:1	Chkd. By: O. POPRAVKA

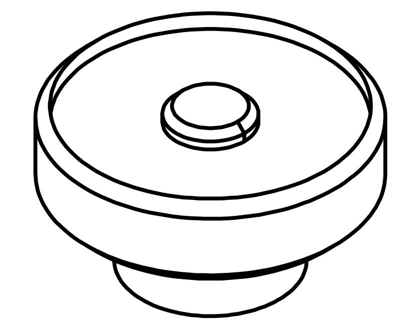




NOTES:
- ALL DIMENSIONS IN INCHES
- TOLERANCES:
    - X.XX ± 0.01
    - X.XXX ± 0.005
- OUTER RADIUS NOT HELD TO TOLERANCE
- SMOOTH SHARP EDGES

Cal Poly Mechanical Engineering SENIOR PROJECT	Team: MUSTANGS ON THE MOON		Title: CRANK ARM		Drwn. By: K. KRAYBILL-VOTH
	Dwg. #:	Nxt Asb:	Date: 4/15/21	Scale: 1:1	Chkd. By: O. POPRAVKA

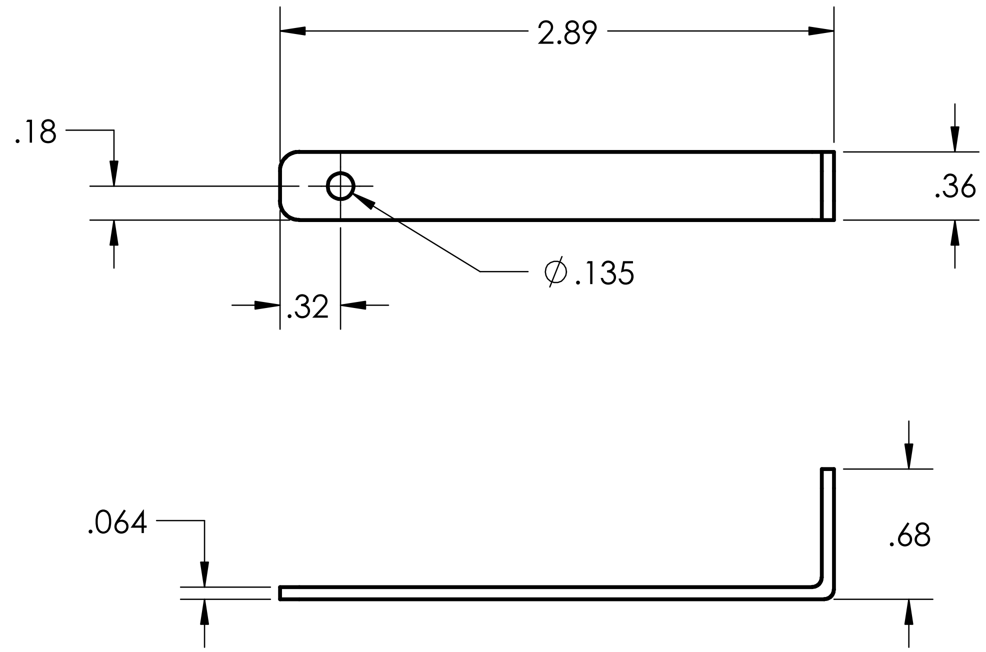




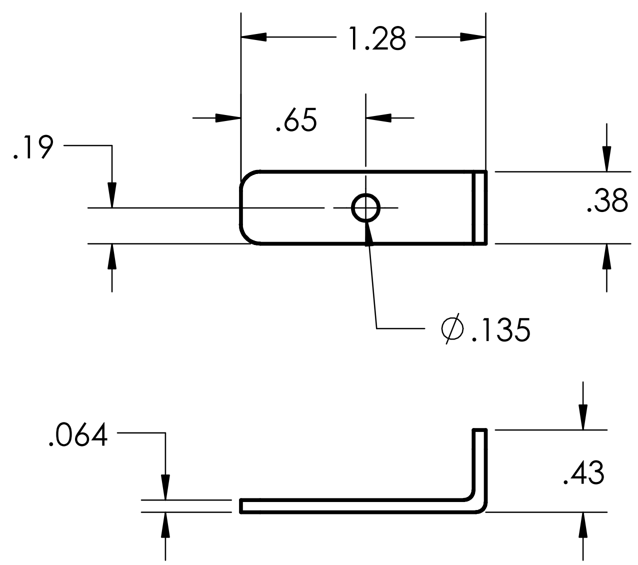
NOTES:

- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- REMOVE SHARP EDGES

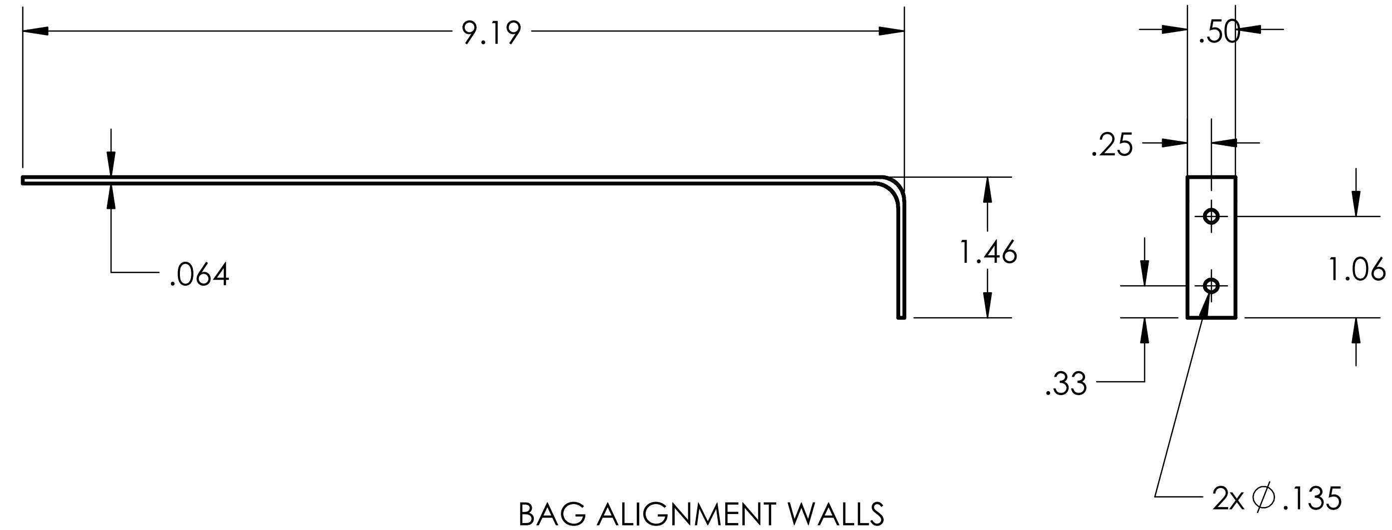
Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON		Title: CRANK HANDLE	Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #:	Nxt Asb:	Date: 6/3/21	Scale: 1:1	Chkd. By: O. POPRAVKA



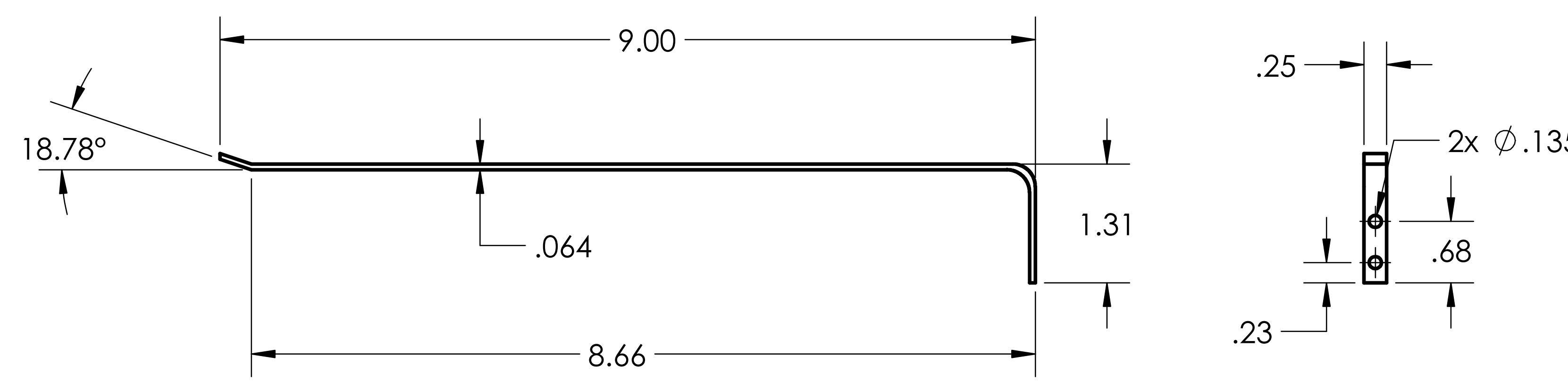
DOOR LOCK: LID SIDE
SCALE: 1:1



DOOR LOCK: DOOR SIDE
SCALE: 1:1

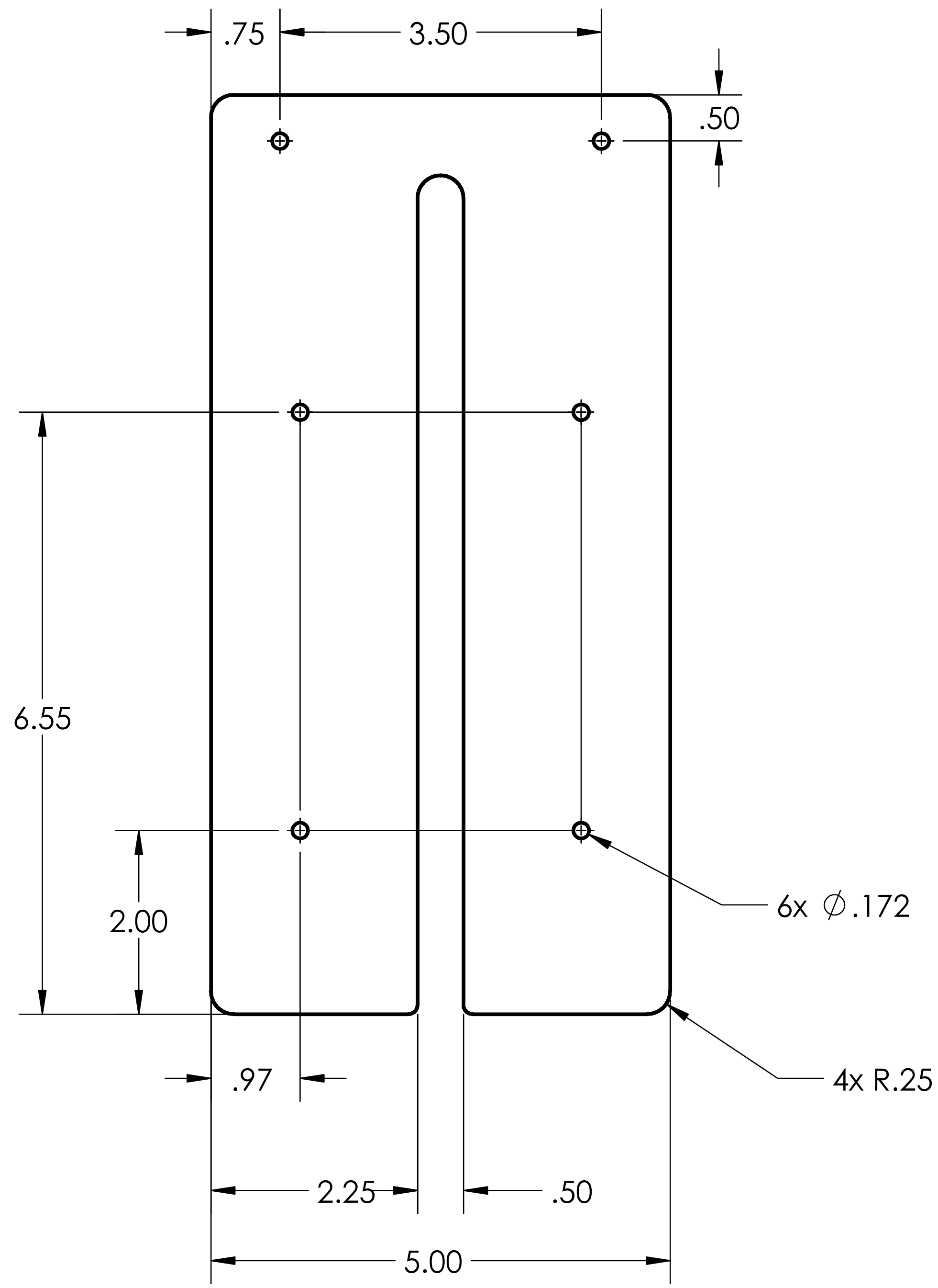


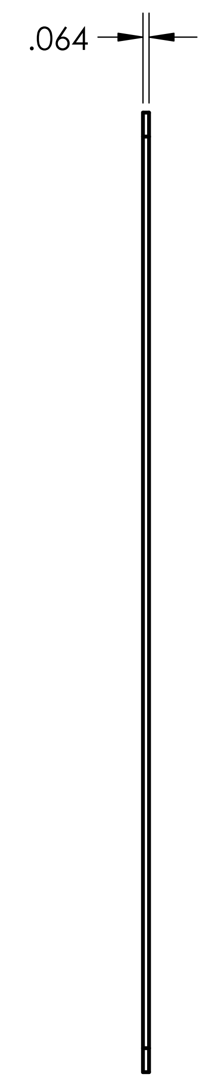
BAG ALIGNMENT WALLS
SCALE 1:2

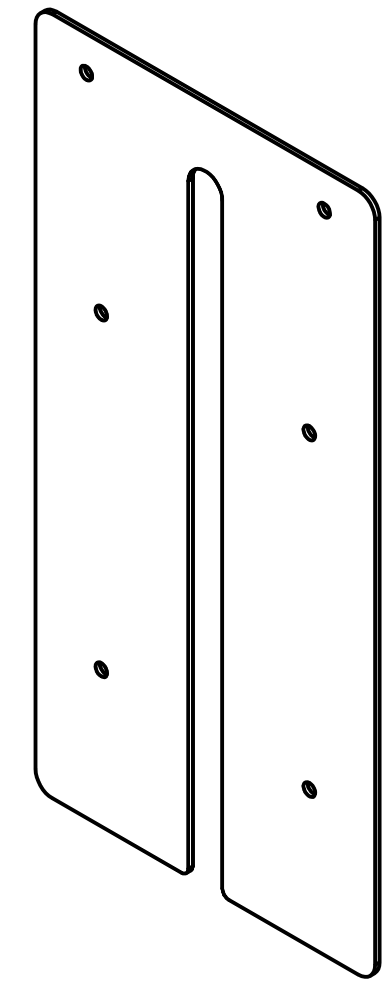


ROD GUIDE RAILS
SCALE: 1:2

Cal Poly Mechanical Engineering SENIOR PROJECT	Team: MUSTANGS ON THE MOON		Title: ALIGNMENT GUIDES		Drwn. By: K. KRAYBILL-VOTH
	Dwg. #:	Nxt Asb:	Date: 6/3/21	Scale: 1:1	Chkd. By: O. POPRAVKA

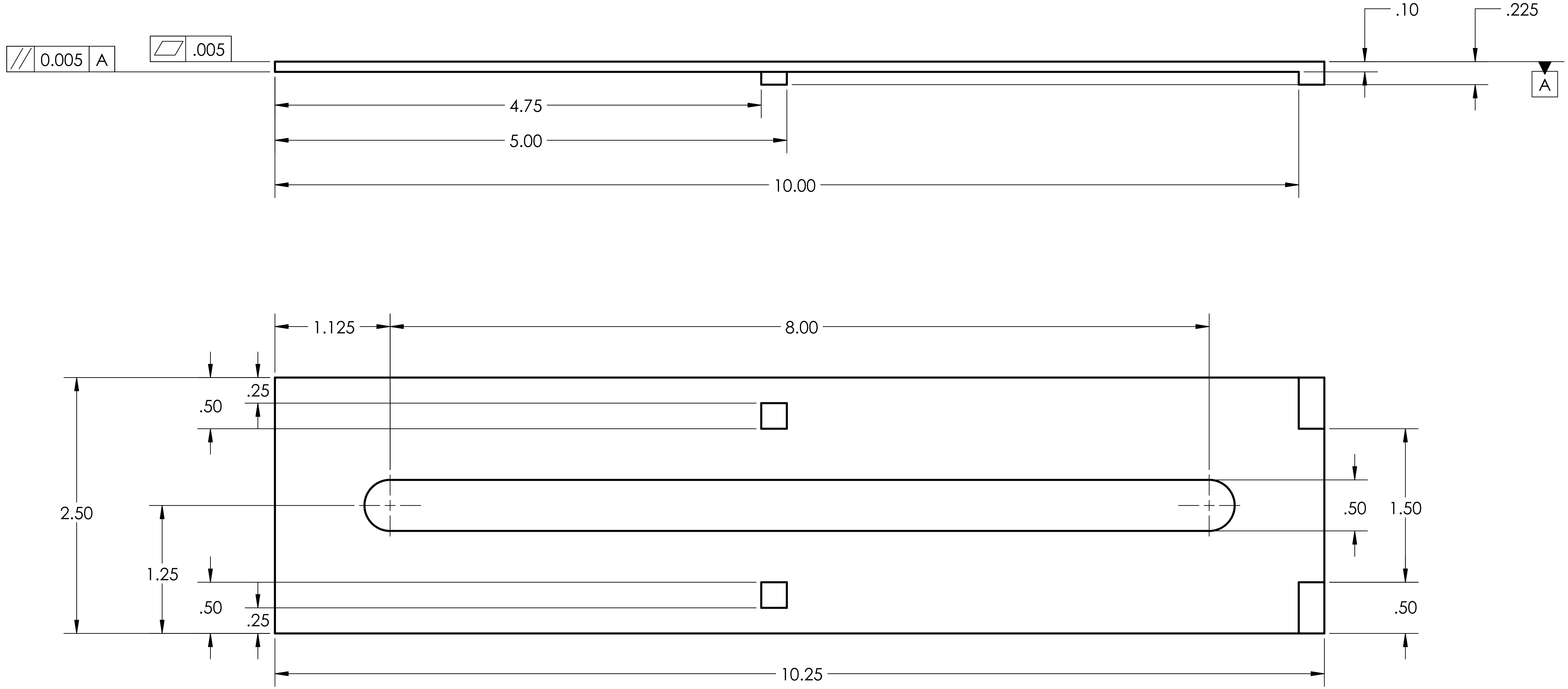






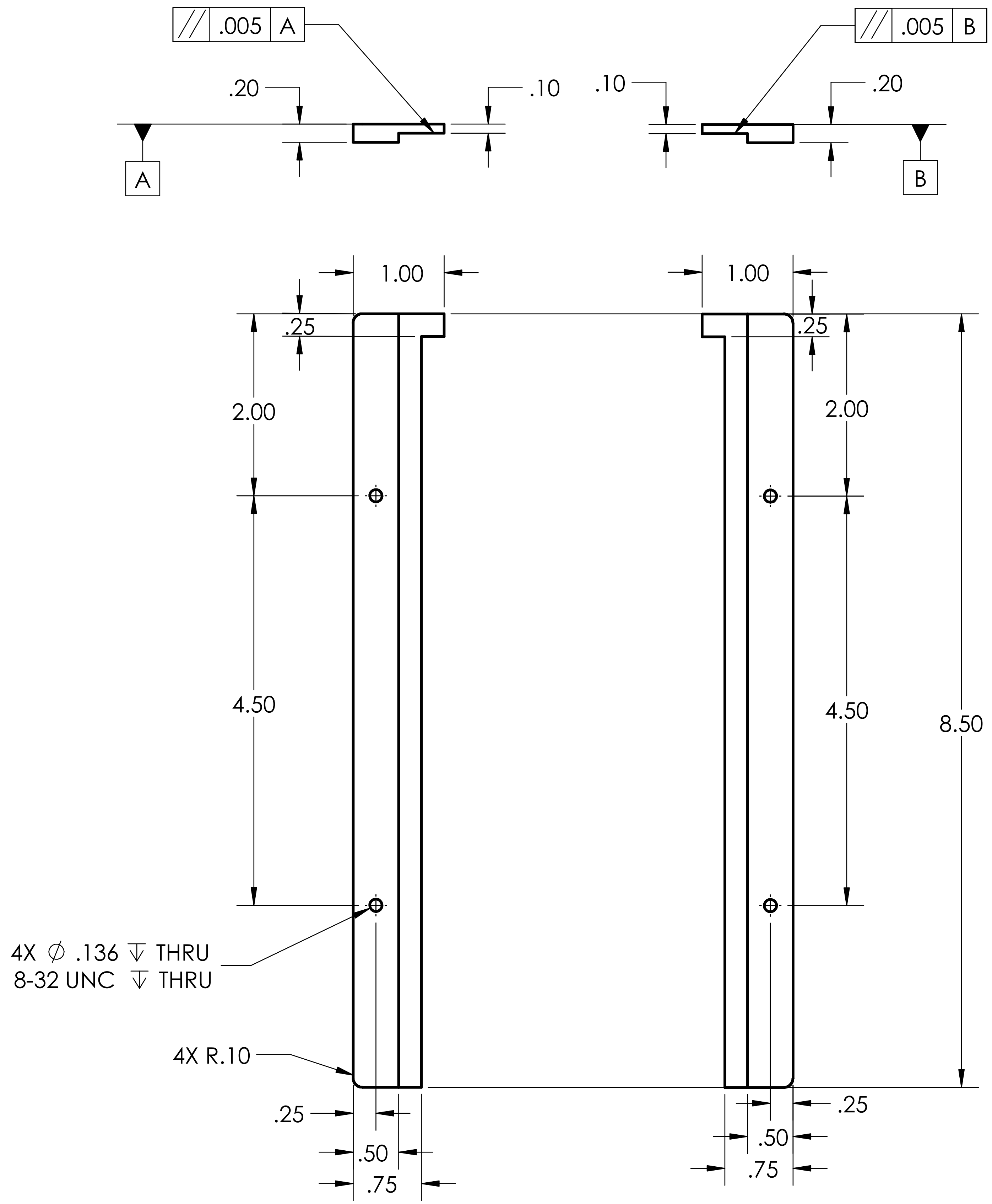
NOTES:
- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- SMOOTH SHARP EDGES
- OUTER RADIUS TOLERANCES ± 0.05

Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON		Title: DOOR PANEL	Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #:	Nxt Asb:	Date: 4/16/21 Scale: 1:2	Chkd. By: O. POPRAVKA



NOTES:
- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- SMOOTH SHARP EDGES

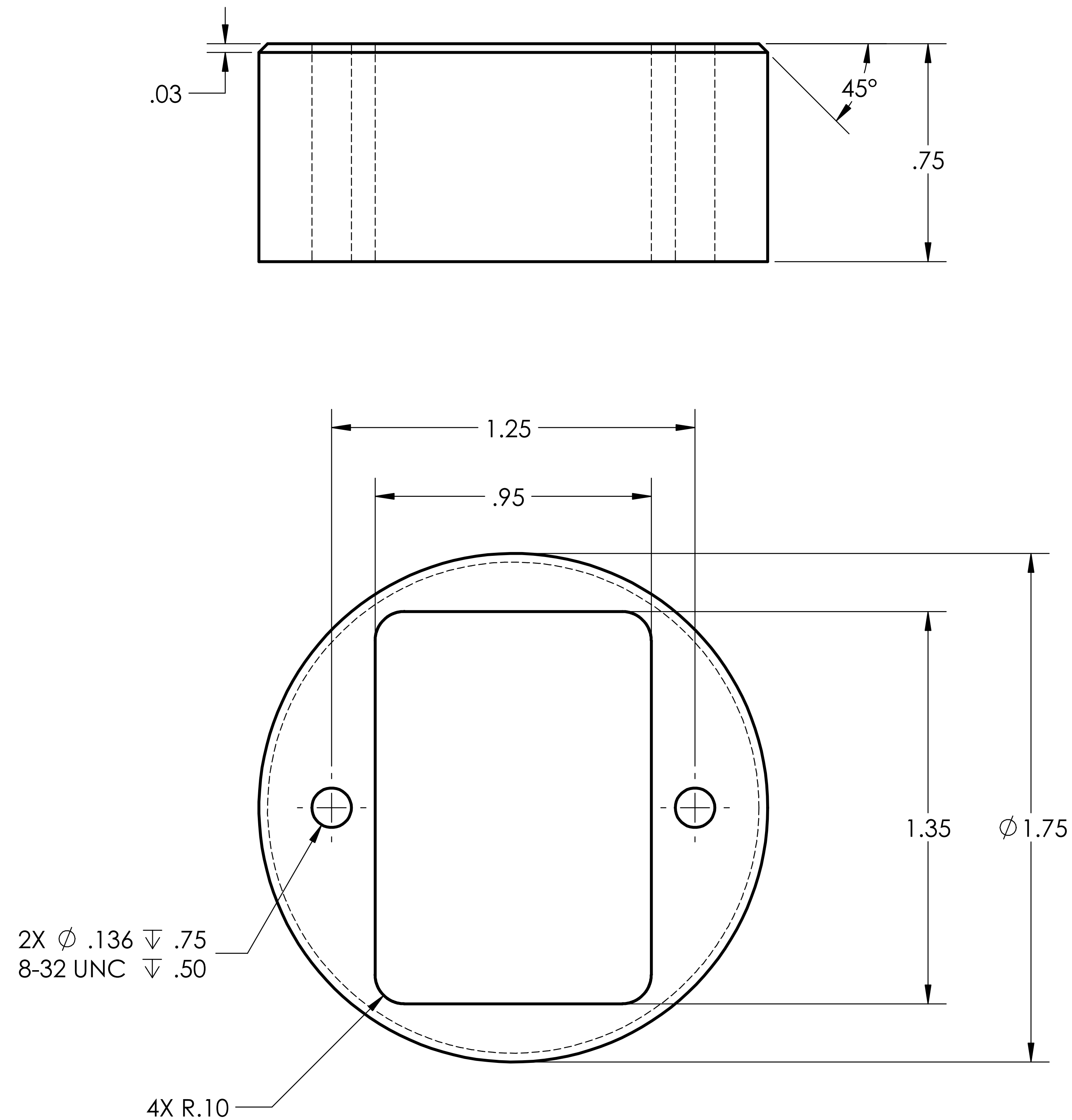
Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON		Title: DOOR SLIDING PANEL		Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #:	Nxt Asb:	Date: 4/16/21	Scale: 1:1	Chkd. By: O. POPRAVKA



NOTES:

- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- SMOOTH SHARP EDGES

Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON		Title: SLIDER GUIDES		Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #:	Nxt Asb:	Date: 4/16/21	Scale: 2:3	Chkd. By: O. POPRAVKA



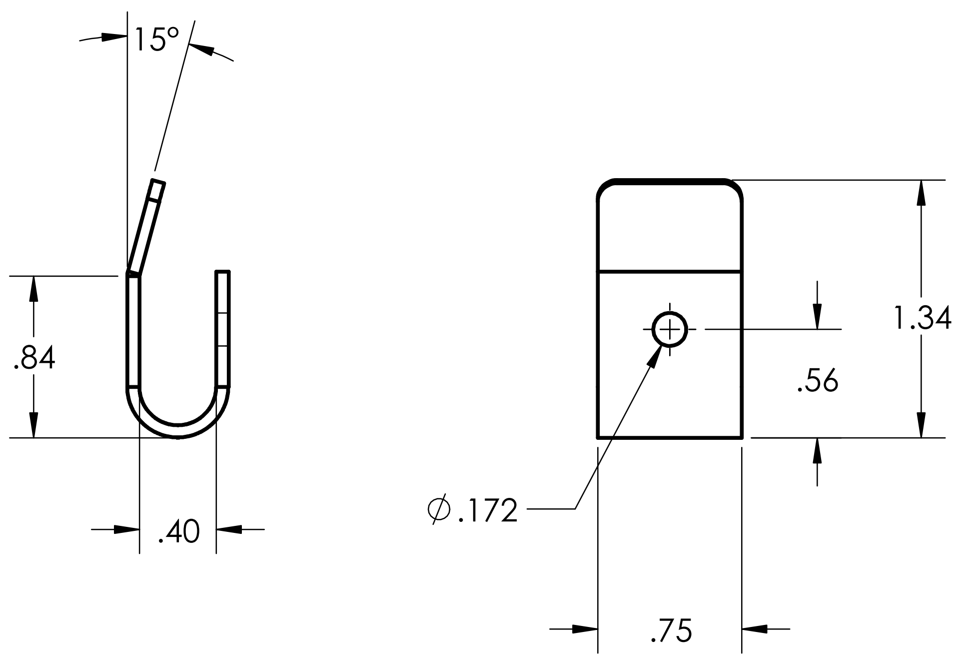
NOTES:

- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- SMOOTH SHARP EDGES

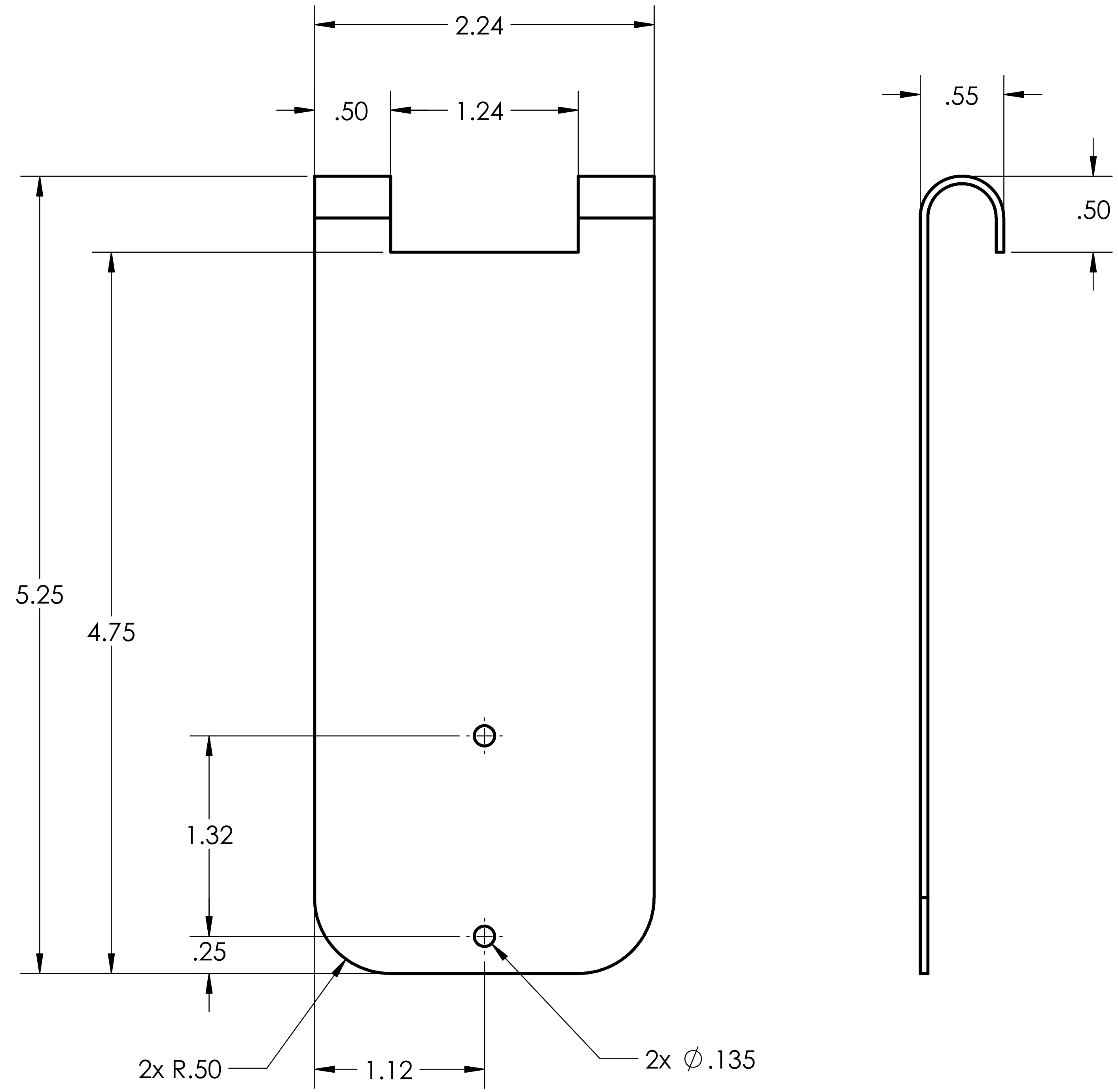
Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON	Title: DOOR KNOB	Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #: / Nxt Asb:	Date: 4/16/21 / Scale: 2:1	Chkd. By: O. POPRAVKA

NOTES:

- ALL DIMENSIONS IN INCHES
- TOLERANCES:
  - X.XX ± 0.01
  - X.XXX ± 0.005
- TAKE CARE IN EXECUTING BEND AROUND CURVED DIE 0.375" IN DIAMETER
- REMOVE SHARP EDGES
- MAKE 2 CONTAINER HOOKS



CONTAINER HOOKS



SLIDING HOOK PANEL

Cal Poly Mechanical Engineering	Team: MUSTANGS ON THE MOON		Title: HOOK PANEL	Drwn. By: K. KRAYBILL-VOTH
SENIOR PROJECT	Dwg. #:	Nxt Asb:	Date: 6/3/21	Scale: 1:1	Chkd. By: O. POPRAVKA

APPENDIX G: PROJECT BUDGET

Senior Project Materials Budget

Title of Project:	F26 NASA Micro-g NExT Sample Container Dispensing Device
Team Members:	Kristin Kraybill-Voth, Kelsey Mickelson, Osccar Popravka
Team Treasurer:	Kristin Kraybill-Voth (kkraybil@calpoly.edu)
Faculty Advisor:	Dr. Mohammad Noori
Sponsor:	NASA Micro-g NExT Design Challenge
Project Start Date:	Fall 2020
Materials Budget:	$500.00 (Senior Project Funding), $400.00 (NASA Stipends)

Updated 5/29/21

Order	Part No.	Description of Item	Vendor	Vendor PN	Qty	Price	S/H/T Est.	Method of Purchase	Date Purchased	Mat'l Location	Notes
Sponsor Order	0151	Al-6061 Rod 1" Dia. X 36" length.	Grainger	2EYG9	1	$ 11.65	$ 36.71	Sponsor	2/16/21	Locker	Coil holder
	0152	Al-6061 1/8"x2"x72"	Grainger	2EYV8	1	$ 8.21		Sponsor	2/16/21	Locker	Crank arm
	0153	Same stock as #0151								Locker	Handle
	0160	Al-6061 1/8"x4"x72"	Grainger	2EYW3	1	$ 23.20		Sponsor	2/16/21	Locker	
	0170	Al-6061 1/4" Dia. X 1' L	Grainger	48KU31	2	$ 1.52		Sponsor	2/16/21	Locker	
	0210	Al-6061 Sheet 0.064" x6"x12"	Grainger	15V219	6	$ 7.65		Sponsor	2/16/21	Locker	
	0220	Al-6061 Sheet 0.187"x3"x36"	Grainger	2EYW7	1	$ 14.23		Sponsor	2/16/21	Locker	
	0230	Al-6061 Sheet 0.187" x2"x36"	Grainger	2EYW5	1	$ 8.42		Sponsor	2/16/21	Locker	
	0240	Same Stock as #0140								Locker	
	0250	1.5" x 2.25" Butt Hinge	Grainger	3HTT8	6	$ 5.09		Sponsor	2/16/21	Locker	
1	0110	Al-6061 Sheet 0.025"x24"x48"	Aircraft Spruce	03-29950	1	$ 28.75	$31.01	Pro-card		Locker	Bag outer walls
McMaster Order #1	0120	Al-6061, 1/8" th. X 1"x12"	McMaster	8975K578	2	$ 1.42	$6.12	Pro-card		Locker	Rotation prevention
	0130	SSTL Compression Spring Stock 0.75" OD	McMaster	9663K87	1	$ -		Pro-card		Returned	Returned and refunded
	0130	SSTL Compression Spring Stock 1" OD	McMaster	9663K94	1	$ -		Pro-card		Returned	Returned and refunded
	0140	Al-6061, 1/8" th. X 1"x12"	McMaster	8975K578	2	$ 1.42		Pro-card		Locker	Hooks
	0260	Same stock as #0140								Locker	
	0270	Al-6061 2" Dia. X 1" Disc	McMaster	1610T15	2	$ 6.32		Pro-card		Locker	
Home Depot Order #1	SP	36 in. x 36 in. Plain Aluminum Sheet in Silver	Home Depot	100351161	1	$ 21.98		Pro-card		Locker	
	SP	1/4 in. x 36 in. Aluminum Round Rod	Home Depot	204273994	1	$ 4.67		Pro-card		Locker	
	SP	1 in. x 48 in. Aluminum Flat Bar with 1/8 in. Thick	Home Depot	204274000	1	$ 10.48		Pro-card		Locker	
K. Mickelson Reimbursements	SP	3D Prints	Steven Hoover			$ 21.00		K. Mickelson	1/21/21	K. Mickelson	
	SP	Acrylic 0.093"x17 7/8"x23 7/8"	Home Depot	202038047	1	$ 13.48	$ 3.76	K. Mickelson	1/30/21	Locker	
	Tools	Plastic Cutter	Home Depot	202038073	1	$ 4.78		K. Mickelson	1/30/21	K. Mickelson	
	Tools	Steel Square	Home Depot	100148335	1	$ 4.97		K. Mickelson	1/30/21	K. Mickelson	
	Tools	Polycast Rafter Square	Home Depot	100154430	1	$ 3.97		K. Mickelson	1/30/21	K. Mickelson	
Sponsor	Tools	Pelican Case	Grainger	20FZ41	1	$ 158.00		Sponsor	4/25/21	K. Kraybill-Voth	
McMaster Order #2	0290	PTFE Unthreaded Spacers - 3/4" OD, 1/4" length	McMaster	95136A350	2	$ 21.96	$65.22	Procard	4/30/21	Locker	Prices shown include qty*price per (varies from above)
	0231	PTFE Unthreaded Spacers - 1/2" OD, 1/4" length	McMaster	95136A230	4	$ 38.12		Procard	4/30/21		
	0160	0.05" th, 6" x 48" Aluminum	McMaster	89015K67	1	$ 25.30		Procard	4/30/21		
	0130	Corrosion-Res. Compression Spring - 1.25" OD	McMaster	9663K41	1	$ 16.09		Procard	4/30/21		
	0161	Stainless Steel Draw Latch	McMaster	6082A12	4	$ 27.08		Procard	4/30/21		
	0250	Polished 304 SSTL strap hinge	McMaster	1364A11	2	$ 23.26		Procard	4/30/21		
	0299	316 SSTL Pan Head Phillips Screws: 1/4"-20, 1/2" lgth	McMaster	91735A537	1	$ 9.83		Procard	4/30/21		
	0299	316 SSTL Pan Head Phillips Screws: 8-32, 1/4" lgth	McMaster	91735A190	1	$ 4.86		Procard	4/30/21		
	0299	316 SSTL Pan Head Phillips Screws: 8-32, 1/2" lgth	McMaster	91735A194	1	$ 5.82		Procard	4/30/21		
	0299	316 SSTL Washers: 8-32	McMaster	90107A010	1	$ 3.45		Procard	4/30/21		
	0000	Chemical Resistant Slippery Teflon PTFE Bar	McMaster	7998K12	1	$ 21.87		Procard	4/30/21		
McMaster Order #3	0130	Corrosion-Res. Compression Spring - 1.25" OD	McMaster	9663K41	1	$ -	$ 10.28	Procard	5/4/21	Returned	Returned and refunded
	0151	Multipurpose 6061 Aluminum 2" diameter, 1" length	McMaster	1610T15	3	$ 18.96		Procard	5/5/21		

Senior Project Budget:	$ 500.00
Actual Expense:	$ 413.43
Remaining Balance:	$ 86.57

NASA Stipend Budget:	$ 750.00
Actual Expense:	$ 181.90
Remaining Balance:	$ 568.10

APPENDIX H: ANALYSES AND SUPPORTING DESIGN MATERIAL

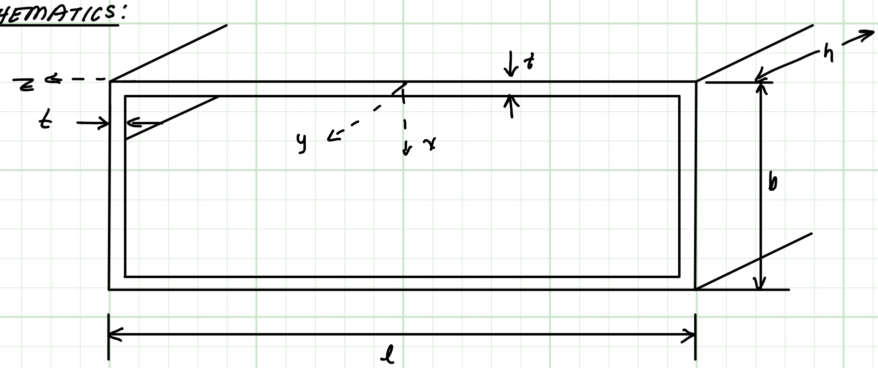
Table 13. Requirement Compliance Matrix.

Requirement	**Compliance**
The dispenser shall hold 20 sample bags.	Our rolled-up bag storage allows the device to be sized to hold up to 20 bags.
The dispenser shall allow the crew member to use one hand to open a single sample bag while attached to the dispenser.	The exposed aluminum tabs allow for the bags to be maneuvered with one hand. The container hooks and resting hooks allow the bag to be positioned first, allowing one hand to operate the door and the sliding hook.
The dispenser shall restrain the sample bags enough to prevent bag damage, deformation, or accidental opening when not in use.	The bags are enclosed in a compartment. The images in Figures 1 and 2 show holes which have been added to indicate lightweighting, though these holes may be covered with Teflon to create additional protection for the bags.
The dispenser shall be capable of holding an open bag that will be filled with a sample (up to 2 lbs) prior to dispensing the filled bag.	Once the bag is open, it will remain on the upwards facing resting hooks for the user to fill the bag with their desired sample. The bottom of the bag will be supported by the door and wall of the container.
The device shall use only manual power.	No electrical power is used. The device relies only on manual power to actuate the door and sliding hook.
The device shall fit within a volume of *12"x12"x5"*	Our current design has a maximum stowed configuration volume of 10.42"x 9.5"x4.07".
The device shall have a 4-hole bolt pattern to interface with the Utility Belt.	4-hole bolt pattern integrated on the rear face of the container for interface with Utility Belt/tool carrier.
The device must be operable with EVA gloved hands.	The exposed aluminum tabs will allow for Astronauts to maneuver the bags, and the mechanisms have large handles designed to be operated with EVA gloves.
The total weight of the dispenser should be less than 3 lbs, not including sample bags.	Initial CAD models are only representational of the concept. During detailed design, engineering analysis will account for the structural integrity of the container while minimizing the amount of material.
The device must not have holes or openings which would allow/cause entrapment of fingers.	Holes and openings that may be incorporated in the design will be covered with Teflon film to eliminate chances for the entrapment of fingers.
The device should be made from only Aluminum 6061, Aluminum 7075, Stainless Steel (any series), or Teflon.	We are using Aluminum 6061 for the structure of our design. We may include Teflon to enclose the side of our design if deemed necessary in testing.
There shall be no sharp edges on the tool.	We have included fillets on all of our edges to limit sharp edges.
Pinch points should be minimized and labeled.	The rotating door has approximately 0.8" clearance to the container wall when closed. Pinch points will be labelled at the door limiter mechanism. The limiter mechanism could alternatively be developed from a soft, flexible material such as Teflon to prevent pinching.

Bag Container & Door Calculations

OBJECTIVE: SELECT APPROPRIATE DIMENSIONS FOR BAG CONTAINER OF M.O.O.D.

SCHEMATICS:



VARIABLES:

l = LENGTH OF CONTAINER
h = HEIGHT OF CONTAINER
b = WIDTH OF SLOT WALL
t_w = THICKNESS OF CONTAINER WALL
t_s = THICKNESS OF SLOT WALL

GIVENS:

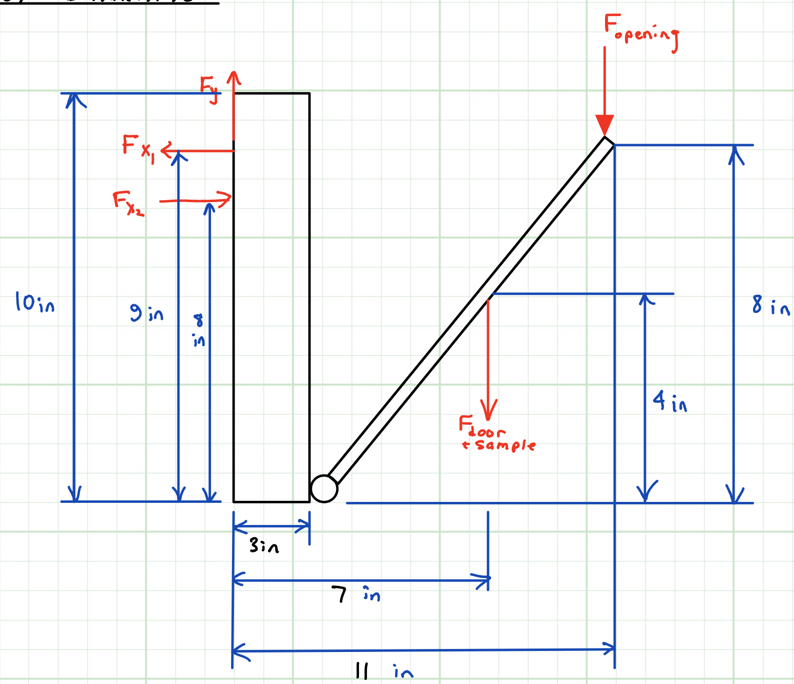
- ALUMINUM:
  - $E = 10 \times 10^6$ psi
  - $S_y = 35 \times 10^3$ psi
  - $\rho =$
- MAXIMUM ALLOWABLE DEFLECTIONS: $\delta_{max} = 0.100''$
- SAFETY FACTOR: 2

FIND:

- APPROPRIATE THICKNESS FOR EACH TYPE OF MATERIAL GIVEN THE LOADING CONDITIONS
- CALCULATE BEARING STRESSES AT 4-HOLE BOLT PATTERN

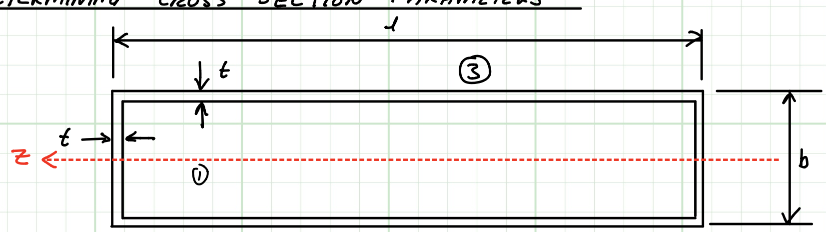
CONT. NEXT PAGE

FREE BODY DIAGRAMS:



BECAUSE THERE ARE SEVERAL COMPONENTS CONNECTED TOGETHER, MUST SEPARATE COMPONENTS AND FIND REACTION FORCES BETWEEN COMPONENTS.

DETERMINING CROSS-SECTION PARAMETERS



AREA: $A = (l \cdot b) - [(l - 2t)(b - 2t)]$

$= lb - [lb - 2tb - 2tl + 4t]$

$$\boxed{A = 2tb + 2tl - 4t}$$

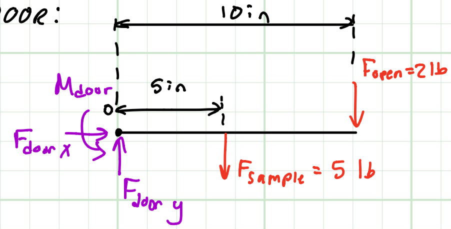
→ MOMENTS OF INERTIA:

$$I_{zz} = \frac{1}{12} l b^3 - \frac{1}{12} \underbrace{(l - 2t)}_{j} \underbrace{(b - 2t)}_{k}^3$$

CONT. NEXT PAGE

OPENING DOOR USE CASE: (EXAGGERATED)

DOOR:



ΣF_y: $0 = +F_{door\,y} - F_{sample} - F_{door}$

$F_{door\,y} = \underline{5lb + 2lb = 7lb}$

ΣF_x: $\underline{0 = F_{door\,x}}$

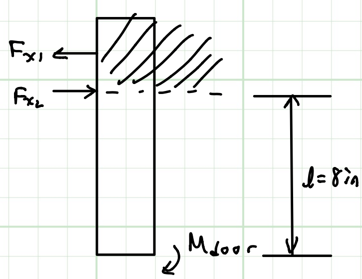
$$\Sigma M_O \; +\circlearrowleft : \quad 0 = M_{door} - F_{sample} \cdot (5in) - F_{open}\,(10in)$$

$$M_{door} = (5lb)(5in) + (2lb)(20in)$$

$$M_{door} = 25in\cdot lb + 40in\cdot lb$$

$$M_{door} = 60\,in\cdot lb$$

TREAT CONTAINER AS CANTILEVER MOMENT LOAD



$$\delta_{max} = \frac{M l^2}{2EI}$$

$$\sigma_{max} = \frac{My}{I}$$

$$SF_\delta = \frac{\delta_{allowable}}{\delta_{max}} \qquad SF_\sigma = \frac{2 \times \sigma_{yield\,al}}{\sigma_{max}}$$

BEARING STRESS:

$$\sigma_{BR} = \frac{F_{y\,max}}{2t_{BR} \cdot d}$$

Bag Container Calculations

Kristin Kraybill-Voth

Edited: 2/15/21

This code is constructed to conduct analysis on the bag container structure for MOOD (coil). The structure is simplified to a rectangular prism with no top or bottom, which underestimates the stiffness due to geometry.

Housekeeping

```
clear;
clc;
```

Variables

```
l = 12;         % [inches] Length of bag container
h = 10;          % [inches] Height of bag container
b = 3;      % [inches] Width of side panel wall
t = 0.019;      % [inches] Thickness of container walls
```

Givens

```
d_AL = 0.1;          % Density of Aluminum [lbf/in^3]
E_AL = 1E7;          % Modulus of Elasticity of Aluminum [psi]
Y_AL = 35000;        % Yield Strength of Aluminum [psi]
Su = 45000;          % [psi]
dmax = 0.100;        % [in] Maximum deflection allowable
```

Area Moment of Inertia

```
j = (l-2*t);
k = (b - 2*t);

Izz = (1/12)*l*b^3 - (1/12)*j*k^3;
```

Typical Door Opening Use

```
Mdoor = 60;      % [ in-lb]
x_dist = 8;          % [in]
dmax_typ = (Mdoor*x_dist^2)/(2*E_AL*Izz)
```

```
dmax_typ = 1.7529e-04
```

```
disp(dmax_typ)
```

```
   1.7529e-04
```

```
sf_displacement = dmax/dmax_typ;
```

```
disp(sf_displacement)
```

```
   570.4952
```

```
sigma_max_typ = (Mdoor*h/2)/(Izz);
disp(sigma_max_typ)
```

```
   273.8848
```

```
sf_stress = (2*Y_AL)/sigma_max_typ;
disp(sf_stress)
```

```
   255.5819
```

```
if dmax_typ < (dmax)
    disp('Passes deflection criteria')
else
    disp('Does not pass deflection criteria')
end
```

```
Passes deflection criteria
```

```
if sigma_max_typ < (2*Y_AL)
    disp('Passes strength criteria')
else
    disp('Does not pass strength criteria')
end
```

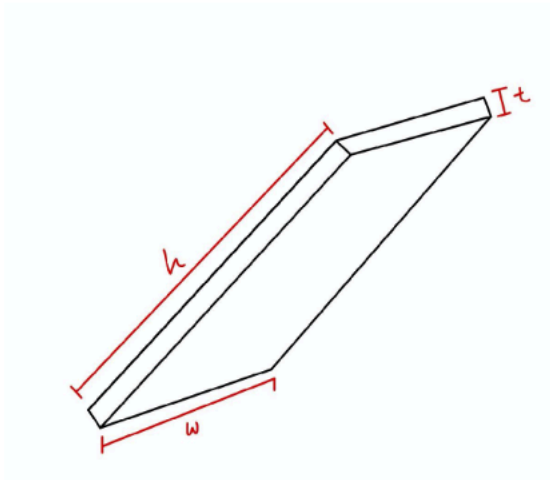
```
Passes strength criteria
```

Bearing Stress

```
fymax = 7;            % [lb] Maximum force on the holes
tbr = t;                % [in] Bearing thickness / thickness wall
d = 0.201;               % [in] Diameter of the holes
sigma_br = fymax/(2*tbr*d);
sigma_br_allow = 1.5*Su;
if (2*sigma_br) < sigma_br_allow
    disp('Passes bearing criteria')
else
    disp('Does not pass bearing criteria')
end
```

```
Passes bearing criteria
```

Door Calculations



Overall Dimensions

```
h = 5;          % [inches]
w = 2.5;        % [inches]
t = 0.1;        % [inches]
```

Slot Dimensions

```
h_slot = 8.5;  % [inches]
w_slot = 0.5;  % [inches]
```

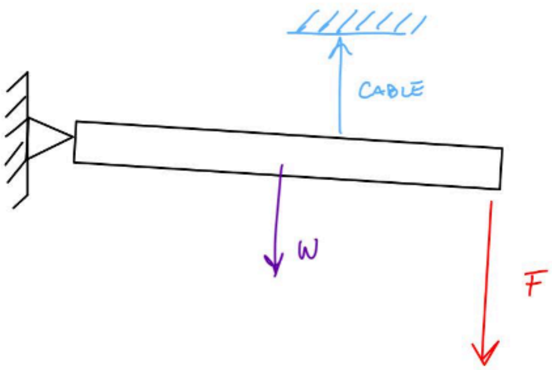
Material Data

```
d_AL = 0.1;          % Density of Aluminum [lbf/in^3]
d_SSTL = 0.285;      % Density of Stainless Steel [lbf/in^3]
d_TFLN = 0.079;      % Density of Teflon [lbf/in^3]

E_AL = 1E7;          % Modulus of Elasticity of Aluminum [psi]
E_SSTL = 2.9E7;      % Modulus of Elasticity of Stainless Steel [psi]
E_TFLN = 1.75E5;     % Modulus of Elasticity of Teflon [psi]

Y_AL = 40000;        % Yield Strength of Aluminum [psi]
Y_SSTL = 30000;      % Yield Strength of Stainless Steel [psi]
Y_TFLN = 6000;       % Yield Strength of Teflon [psi]
```

Area Moment of Inertia

```
Iz = (w*(t^3))/12;  % [in^4]
```

Case 1: Opening the Door

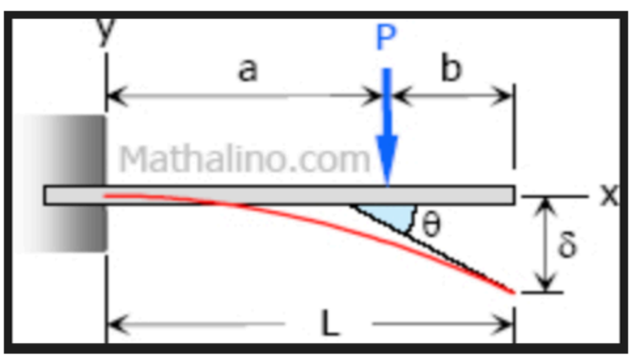



```
F_open = 2;          % [lbf]
W = h*w*t*d_AL;      % [lbf]
```

From Force opening the door

```
delta_F_open = (F_open*(h^3))/(3*E_AL*Iz);  % [in]
M_max_open = F_open*h;                      % [lbfin]
y = t/2;                                    % [in]
sigma_F_open = (M_max_open*y)/Iz;           % [psi]
```

From the Weight




```
a = h/2;                      % [in]
b = h/2;                      % [in]
delta_W = ((W*(a^2))...       % [in]
```

```
    /(6*E_AL*Iz))*((3*h)-a);
M_max_W = W*a;              % [lbfin]
y = t/2;                    % [in]
sigma_W = (M_max_W*y)/Iz;   % [psi]
```

Total Deflection

```
delta_tot = delta_F_open + delta_W;      % Superposition
display(delta_tot);                      % Total Deflection [inches]
```

```
delta_tot = 0.0408
```

```
delta_max = 0.1;        % [inches]

if delta_tot <= delta_max
    deflection = sprintf('Passed');
else
    deflection = sprintf('Failed');
end

display(deflection);
```

```
deflection = 'Passed'
```

Total Stress

```
sigma_tot = sigma_F_open + sigma_W;      % [psi]
display(sigma_tot);
```

```
sigma_tot = 2.4750e+03
```

```

sigma_max = Y_AL;

if sigma_tot <= sigma_max
    stress = sprintf('Passed');
else
    stress = sprintf('Failed');
end

display(stress);
```

```
stress = 'Passed'
```

APPENDIX I: FAILURE MODES, EFFECTS & ANALYSES

Design Failure Mode and Effects Analysis

Product: ____________________________ Prepared by: ____________________________

Team: ____________________________ Date: ________________ (orig)

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
Container / Contain Bags	Bags aren't contained	a) Bags fall out b) Space debris	5	a) Structure breaks b) Attachment points fail c) Coil detaches/moves	a) Structural analysis b) Detailed design c) Testing	2	User group testing, prototyping			Add design feature for additional constraint	Kristin 5/15/21	Design includes restraints			
Container / Hold multiple bags	Does not hold multiple bags	a) Cannot collect multiple samples	6	a) Coil jammed b) Incorrect sizing	a) Detailed design	3	Testing			Design to specifications	Kelsey 5/1/21	Coil design			
Container / Bag Dispensing	Bags do not dispense	a) Cannot remove bags b) Bags are damaged c) Reduced ease-of-use d) Cannot collect samples	6	a) Improper loading b) Coil jams	a) Testing coil mechanism b) Documenting loading procedure	2	Testing			Identify issues in early functionality testing	Team 5/6/21				
Container / Protect Bags	Bags get damaged	a) Contamination b) Cannot collect samples	7	a) Open parts of the compartment b) Dispenser falls c) Pinch points d) Bags torn on sharp edge	a) Detailed design b) Proper manufacturing precautions	2	Inspection			Design enclosed container	Kristin 4/26/21	Designed			
Container / Prevent Contamination	Samples are contaminated	a) Samples aren't usable	7	a) Bags not contained b) Astronaut has to use hand to open bag c) Using un-approved materials	a) Material selection b) User testing	2	Testing			Separate bags during storage	Team 4/1/21				
Door Latch / Keep Door Closed	Door opens when not in use, hooks exposed	a) Door gets damaged b) Hooks snag astronaut c) Does not fit in allotted volume	9	a) Lock mechanism doesn't work b) Hinge jammed c) Lock mechanism not used	a) Mechanism testing b) Detailed design	2	Testing			Design door latch with easy manipulation	Oscar 5/10/21				
4-bolt Pattern / Attach to Carrier	Dispenser can't be mounted	a) Dispenser unusable	8	a) Material too thin around pattern b) Incorrect tolerancing	a) Detailed design and analysis	1	Calculations			Design to specifications	Kristin 4/1/21	Designed			
Sliding Hook / Pulling bag out of container	Hook doesn't grab bag tab	a) Can't dispense bag b) May have to manually unjam	5	a) Improper dispensing b) Mechanism jammed	a) Testing	2	Prototyping and Testing			Identify issues in early functionality testing	Oscar 5/2/21				
Sliding Hook / Slider Motion	Slider doesn't move	a) Slider unusable b) Unable to open sample bags	6	a) Debris entrapment b) Improper tolerancing	a) Testing with debris b) User testing c) Mechanism testing d) Detailed design	1	Prototyping and Testing (land and water)			Modify tolerances	Team 5/15/21				
Sliding Hook / Open Bag with One Hand	Dispenser can't be operated with one hand	a) Unable to collect samples b) Poor user experience	4	a) Sliding hook breaks b) Mechanism jammed c) Incorrect sizing for glove	a) User testing b) Mechanism testing c) Detailed design	2	Prototyping, Testing, User Feedback			Adjust ergonomics	Kelsey 5/2/21				
Container Hook / Catching other tab	Tab not grabbed on container side	a) Have to manually place tab b) Poor user experience / cannot use one hand	4	a) Mechanism not sized b) Unclear operational steps	a) User testing b) Documentation	2	Prototyping, Testing			Identify issues in early functionality testing	Team 5/8/21				

Design Failure Mode and Effects Analysis

Product: ____________________________ Prepared by: ____________________________

Team: ____________________________ Date: ________________ (orig)

												Action Results			
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Door / Keep Bag Open	Bags don't stay open	a) Difficult to collect samples	6	a) Door gets jammed b) Lock breaks c) Door doesn't stay open d) Hooks don't stay in bag	a) Mechanism testing b) Detailed design	3	Prototyping and Testing			Testing	Team 5/5/21				

APPENDIX J: DESIGN HAZARD CHECKLIST

Y	N	
X		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	X	2. Can any part of the design undergo high accelerations/decelerations?
	X	3. Will the system have any large moving masses or large forces?
	X	4. Will the system produce a projectile?
X		5. Would it be possible for the system to fall under gravity creating injury?
	X	6. Will a user be exposed to overhanging weights as part of the design?
	X	7. Will the system have any sharp edges?
	X	8. Will any part of the electrical systems not be grounded?
	X	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	X	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	X	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	X	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	X	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	X	14. Can the system generate high levels of noise?
X		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	X	16. Is it possible for the system to be used in an unsafe manner?
	X	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The design includes a door mechanism which could create potential pinch points between the door itself and the container, or the two-bar linkage used to limit the motion of the door. Note: the door does rotate freely and would likely not cause accidental entrapment.	During detailed design, it may be determined that Teflon could be used to replace the two-bar linkage, minimizing stiff components which could cause pinching. Additionally, the spacing between the door and container could be offset from the base. These will be explored during additional testing. If the geometry cannot be utilized to minimize pinch points, they will be clearly labelled.	12/1/20 (Detailed design)	
The system could potentially fall under gravity, though it is unlikely to cause injury. The device will be attached to either the utility belt on the Astronaut suits or the tool carrier via a secure 4-bolt interface. However, if the device were to become disconnected, it would fall. This is likely mostly an issue during testing as opposed to actual use on the moon (lower gravity).	The total device weight shall not exceed 3 lbs. Additional precautions will be taken during testing to avoid injury from the device falling by users wearing close-toed shoes. Lastly, sharp edges and corners will be filleted to avoid cuts and abrasions.	2/20/21 (Structural Prototype)	
Our final prototype will be tested under unique underwater conditions of NASA's Neutral Buoyancy Lab. Considering the applications beyond the competition, the device could be used on the moon's surface with the harsh temperatures and vacuum of space, along with lunar dust.	Our device is required to function under only manual power and must be made from any of three materials that are NASA-approved for space conditions. With no power sources beside the user, there are no concerns for the performance underwater or in space. We will ensure our design uses the approved materials which will not react in space conditions.	12/1/20 (Detailed design)	

APPENDIX K: DESIGN VERIFICATION PLAN

DVP&R - Design Verification Plan (& Report)

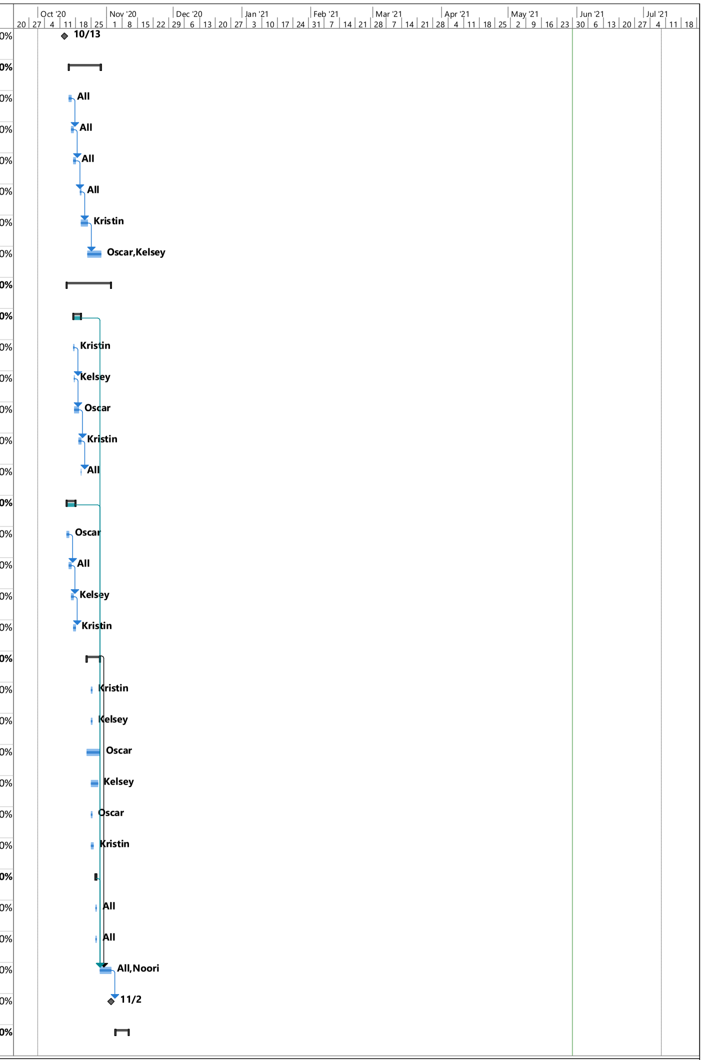
Project: F26 Sample Container Dispensing Device | Sponsor: NASA Micro-g NExT | Edit Date: 2/2/21

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	Holds and dispense 20 bags	Roll and load 20 sample bags in container. Dispense all bags individually.	# bags dispensed properly	Pass/Fail	N/A	Full Assembly, Sample Bags	Oscar	4/29/21			
2	Holds 2 lbs of lunar sample	Use 2 lb weight in terrestrial (on ground) test. Place bag in dispensing container, place sample in bag, lift bag out.	Deflection of door and container	Deflection <0.1"	2 lb weight	Full Asembly, Sample Bags	Kelsey	4/29/21			
3	Terrestrial Ease of Use	Use double-layer glove to operate Sample Container Dispenser through full cycle of operations. Several different operators to test for one handed use. May include additional parameters during test for repeatability, etc.	Qualitative Results (ease of use ranked 1-10)	Pass/Fail, feedback	Two neoprene gloves, snow glove, sample mockup	Full Assembly, Sample Bags	Kristin	5/2/21			
4	Underwater Ease of Use	Use Double-layer glove to operate Sample Container Dispenser through full cycle of operations. Add visual impairment to limit line of sight. Several different operators to test. Perform tests underwater.	Qualitative Results (ease of use ranked 1-10)	Pass/Fail, feedback	Two neoprene gloves, snow glove, sample mockup, goggles, underwater camera, sight limiter, pool	Full Asembly, Sample Bags	All	5/6/21			
5	Bags Remain Contained (Underwater and Terrestrial)	Submerge full assembly with sample bags loaded in water. Move dispense around, then test operation.	Bags Dispense Correctly after Movement	Pass/Fail	Pool, underwater camera	Full Assembly, Sample Bags	Kristin / Oscar	5/6/21			

Complete these columns when you conduct the tests.

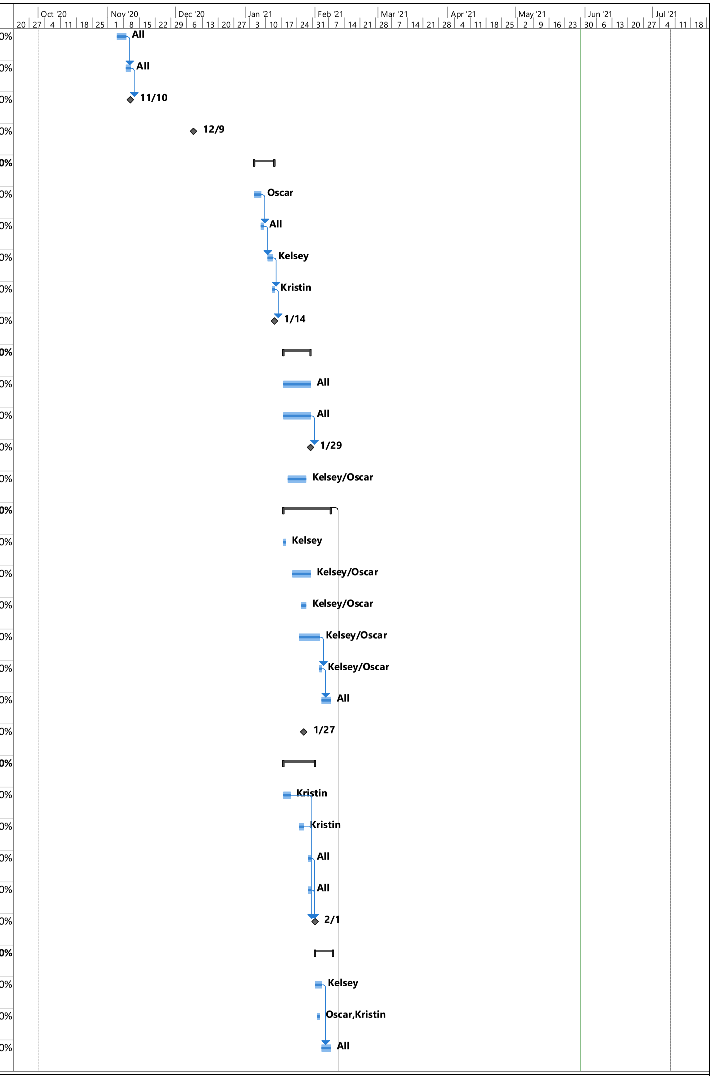
APPENDIX L: GANTT CHART

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names	% Complete
1	SOW Deliverable	0 days	Tue 10/13/2(	Tue 10/13/2(		Kristin	100%
2	**Conceptual Design**	**12.25 day**	**Thu 10/15/2(**	**Thu 10/29/2(**			**100%**
3	Conduct Ideation Session #1	1 day	Thu 10/15/2(	Thu 10/15/2(		All	100%
4	Conduct Ideation Session #2	1 day	Fri 10/16/20	Fri 10/16/20	3	All	100%
5	Conduct Ideation Session #3	1 day	Sat 10/17/20	Sat 10/17/20	4	All	100%
6	Select Concept	2 hrs	Tue 10/20/2(	Tue 10/20/2(	5	All	100%
7	Concept CAD Development	3 days	Tue 10/20/2(	Fri 10/23/20	6	Kristin	100%
8	Build Concept Prototype	0.71 wks	Fri 10/23/20	Thu 10/29/2(	7	Oscar,Kelsey	100%
9	**Micro-g NExT Proposal**	**16 days**	**Wed 10/14/2**	**Mon 11/2/2(**			**100%**
10	**Technical Section**	**2.5 days**	**Sat 10/17/20**	**Tue 10/20/2(**			**100%**
11	Write Abstract	1 hr	Sat 10/17/20	Sat 10/17/20		Kristin	100%
12	Describe Concept	1 hr	Sat 10/17/20	Sat 10/17/20	11	Kelsey	100%
13	Develop Operations Plan	1 day	Sat 10/17/20	Mon 10/19/2	12	Oscar	100%
14	Create Safety Procedure	1 day	Mon 10/19/2	Tue 10/20/2(	13	Kristin	100%
15	Cite Technical References	2 hrs	Tue 10/20/2(	Tue 10/20/2(	14	All	100%
16	**Outreach**	**4 days**	**Wed 10/14/2**	**Sat 10/17/20**			**100%**
17	Coordinate with groups	1 day	Wed 10/14/2	Wed 10/14/2		Oscar	100%
18	Develop Outreach Plan	1 day	Thu 10/15/2(	Thu 10/15/2(	17	All	100%
19	Contact organizations for activities	1 day	Fri 10/16/20	Fri 10/16/20	18	Kelsey	100%
20	Create educational activities	1 day	Sat 10/17/20	Sat 10/17/20	19	Kristin	100%
21	**Administrative Section**	**5 days**	**Fri 10/23/20**	**Wed 10/28/2**			**100%**
22	Select test week preference	1 hr	Sun 10/25/2(	Sun 10/25/2(		Kristin	100%
23	Write request for mentorship	1 hr	Sun 10/25/2(	Sun 10/25/2(		Kelsey	100%
24	Obtain institutional letter of endorsement	0.71 wks	Fri 10/23/20	Wed 10/28/2		Oscar	100%
25	Obtain statement of supervising faculty	3 days	Sun 10/25/2(	Tue 10/27/2(		Kelsey	100%
26	Review statement of rights of use	2 hrs	Sun 10/25/2(	Sun 10/25/2(		Oscar	100%
27	Develop funding and budget statement	1 day	Sun 10/25/2(	Sun 10/25/2(		Kristin	100%
28	**Concept Video**	**0.25 days**	**Tue 10/27/2(**	**Tue 10/27/2(**			**100%**
29	Demonstrate mockup	1 hr	Tue 10/27/2(	Tue 10/27/2(		All	100%
30	Create pitch	2 hrs	Tue 10/27/2(	Tue 10/27/2(		All	100%
31	Proposal Review	3 days	Thu 10/29/2(	Mon 11/2/20	28,21,16,10	All,Noori	100%
32	Proposal Due	0 days	Mon 11/2/20	Mon 11/2/20	31	Kristin	100%
33	**Preliminary Design Review**	**5 days**	**Thu 11/5/20**	**Tue 11/10/2(**			**100%**

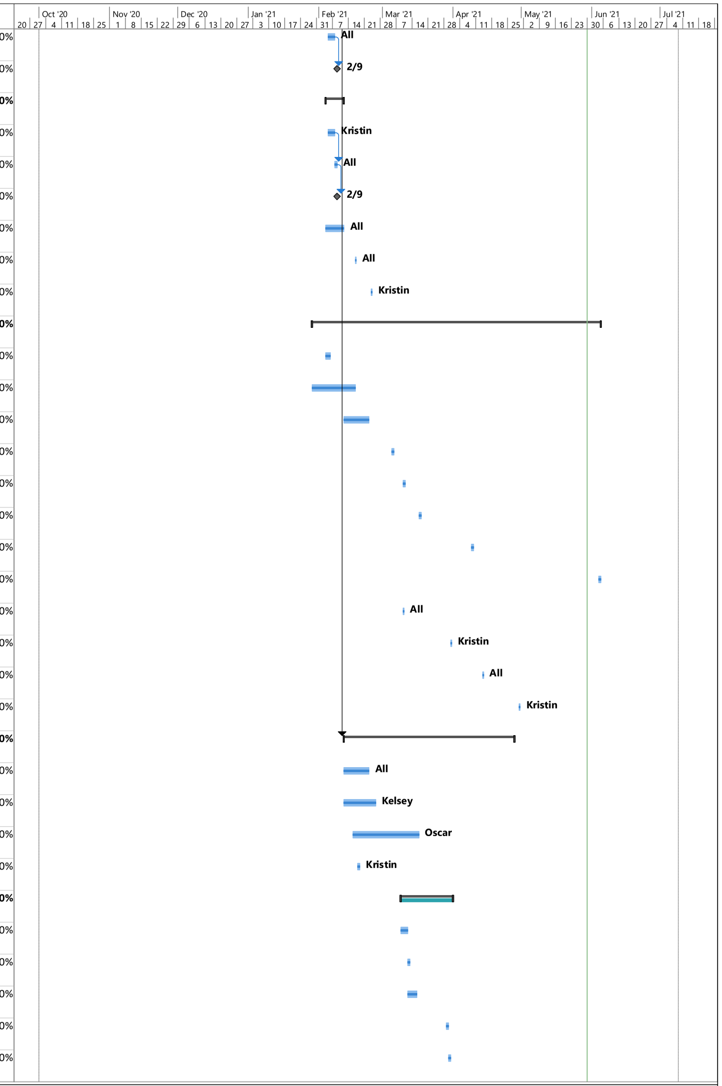


Page 1

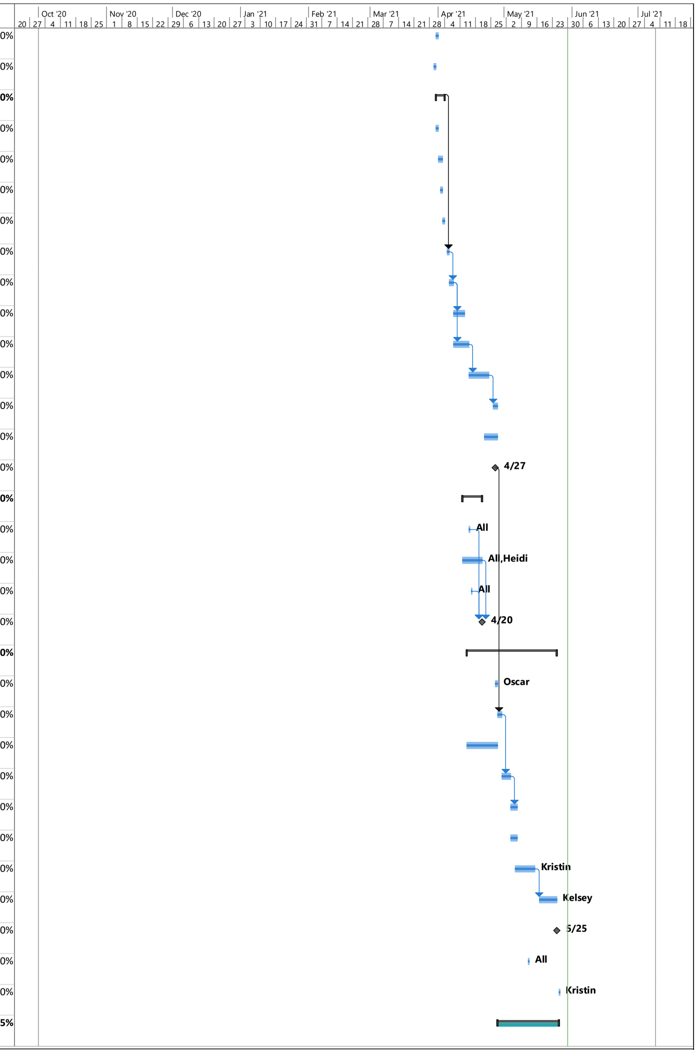
ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names	% Complete
34	Write PDR Report	3 days	Thu 11/5/20	Sun 11/8/20		All	100%
35	Create PDR Slides	2 days	Mon 11/9/20	Tue 11/10/2C	34	All	100%
36	PDR Presentations	0 days	Tue 11/10/2C	Tue 11/10/2C	35	All	100%
37	Receive Competition Selection Decision	0 days	Wed 12/9/20	Wed 12/9/20		NASA	100%
38	**Interim Design Review**	**7 days**	**Tue 1/5/21**	**Thu 1/14/21**			**100%**
39	Conduct Structural Design Analysis	3 days	Tue 1/5/21	Thu 1/7/21		Oscar	100%
40	Select Material	1 day	Fri 1/8/21	Fri 1/8/21	39	All	100%
41	Conduct design analysis for use cases	2 days	Mon 1/11/21	Tue 1/12/21	40	Kelsey	100%
42	Prepare for Design Review	1 day	Wed 1/13/21	Wed 1/13/21	41	Kristin	100%
43	Interim Design Review	0 days	Thu 1/14/21	Thu 1/14/21	42	All	100%
44	**Detailed Design**	**11 days?**	**Mon 1/18/21**	**Fri 1/29/21**			**100%**
45	Manufacturing Feedback	11 days?	Mon 1/18/21	Fri 1/29/21		All	100%
46	Initial Sizing Calculations	11 days?	Mon 1/18/21	Fri 1/29/21		All	100%
47	Calculations Review	0 days	Fri 1/29/21	Fri 1/29/21	46	All	100%
48	Protoype Modifications	7 days?	Wed 1/20/21	Wed 1/27/21		Kelsey/Oscar	100%
49	**Create Structural Prototype**	**17 days**	**Mon 1/18/21**	**Sun 2/7/21**		**All**	**100%**
50	Identify 3D printing resources	1 day	Mon 1/18/21	Mon 1/18/21		Kelsey	100%
51	Manufacturing plan	7 days	Fri 1/22/21	Fri 1/29/21		Kelsey/Oscar	100%
52	Configure Design for Manufacturing	2 days	Tue 1/26/21	Wed 1/27/21		Kelsey/Oscar	100%
53	Manufacturing	1 wk	Mon 1/25/21	Tue 2/2/21		Kelsey/Oscar	100%
54	Assembly	1 day	Wed 2/3/21	Wed 2/3/21	53	Kelsey/Oscar	100%
55	Structural Prototype Testing	3 days	Thu 2/4/21	Sun 2/7/21	54	All	100%
56	Micro-g NExT January Status Report	0 days	Wed 1/27/21	Wed 1/27/21		Kristin	100%
57	**Micro-g Next Milestone 1**	**11 days**	**Mon 1/18/21**	**Mon 2/1/21**			**100%**
58	1A: Team Proposal Feedback Response	3 days	Mon 1/18/21	Wed 1/20/21		Kristin	100%
59	1B: Team Project Timeline	2 days	Mon 1/25/21	Tue 1/26/21		Kristin	100%
60	1C: Team Introduction Video	1 day	Fri 1/29/21	Fri 1/29/21		All	100%
61	1D: Participant Profile Survey	1 day	Fri 1/29/21	Fri 1/29/21		All	100%
62	Complete Milestones	0 days	Mon 2/1/21	Mon 2/1/21	58,59,60,61		100%
63	**Senior Project Critical Design Review**	**7 days**	**Mon 2/1/21**	**Tue 2/9/21**			**100%**
64	Create and verify manufacturing plan	3 days	Mon 2/1/21	Wed 2/3/21		Kelsey	100%
65	Check-in for NASA requirements	1 day	Tue 2/2/21	Tue 2/2/21		Oscar,Kristin	100%
66	Write CDR Report	3 days	Thu 2/4/21	Sun 2/7/21	64	All	100%



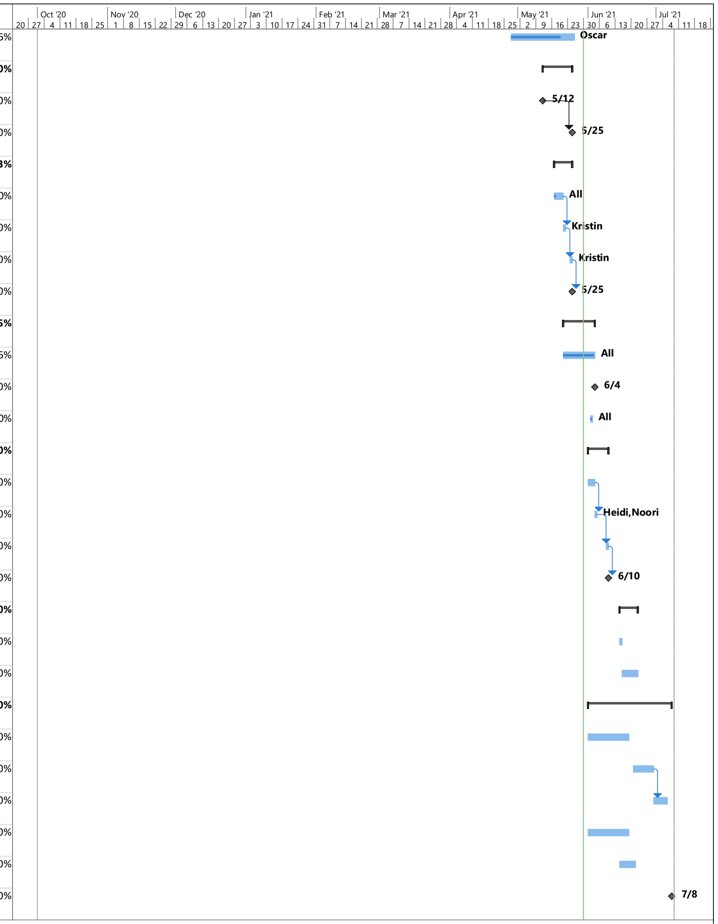
ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names	% Complete
67	Develop presentation material for CDR	2 days	Fri 2/5/21	Sun 2/7/21		All	100%
68	CDR in Class	0 days	Tue 2/9/21	Tue 2/9/21	67	All	100%
69	**Micro-g NExT Milestone 2**	**7 days**	**Thu 2/4/21**	**Thu 2/11/21**			**100%**
70	Develop PDR Power Point	2 days	Fri 2/5/21	Sun 2/7/21		Kristin	100%
71	Practice PDR Presentation	1 day	Mon 2/8/21	Mon 2/8/21	70	All	100%
72	2A: PDR Presentation	0 days	Tue 2/9/21	Tue 2/9/21	71	All	100%
73	2B: Materials List and Manufacturing Items	1 wk	Thu 2/4/21	Thu 2/11/21		All	100%
74	Micro-g NExT Focus Session 2	1 hr	Wed 2/17/21	Wed 2/17/21		All	100%
75	Micro-g NExT February Status Report	2 hrs	Wed 2/24/21	Wed 2/24/21		Kristin	100%
76	**Outreach**	**94 days**	**Fri 1/29/21**	**Fri 6/4/21**			**100%**
77	Attend SEEC 2021	2 days	Thu 2/4/21	Fri 2/5/21			100%
78	Modify Lesson Plans	2 wks	Fri 1/29/21	Tue 2/16/21			100%
79	Obtain Materials	1 wk	Fri 2/12/21	Mon 2/22/21			100%
80	SLOCA Lunar History Lesson	1 day	Fri 3/5/21	Fri 3/5/21			100%
81	SLOCA Moon Lander Lesson 1	1 day	Wed 3/10/21	Wed 3/10/21			100%
82	SLOCA Moon Lander Lesson 2	1 day	Wed 3/17/21	Wed 3/17/21			100%
83	SLOCA Interactive Astornomy Lesson	1 day	Fri 4/9/21	Fri 4/9/21			100%
84	Cal Poly Senior Project Showcase	1 day	Fri 6/4/21	Fri 6/4/21			100%
85	Micro-g NExT Focus Session 3	1 hr	Wed 3/10/21	Wed 3/10/21		All	100%
86	Micro-g NExT March Status Report	2 hrs	Wed 3/31/21	Wed 3/31/21		Kristin	100%
87	Micro-g NExT Focus Session 4	1 hr	Wed 4/14/21	Wed 4/14/21		All	100%
88	Micro-g NExT April Status Report	2 hrs	Fri 4/30/21	Fri 4/30/21		Kristin	100%
89	**Verification (Final) Prototype Build**	**54 days**	**Fri 2/12/21**	**Tue 4/27/21**	**49**		**100%**
90	Finalize manufacturing plan	1 wk	Fri 2/12/21	Mon 2/22/21		All	100%
91	Finalize CAD	10 days	Fri 2/12/21	Thu 2/25/21		Kelsey	100%
92	Obtain COTS components	3 wks	Tue 2/16/21	Tue 3/16/21		Oscar	100%
93	Yellow Tag Certifications	1 day	Thu 2/18/21	Thu 2/18/21		Kristin	100%
94	**Machine sheet metal components**	**17 days**	**Tue 3/9/21**	**Wed 3/31/21**		**All**	**100%**
95	Waterjet box pattern	3 days	Tue 3/9/21	Thu 3/11/21			100%
96	Sheet metal bending	1 day	Fri 3/12/21	Fri 3/12/21			100%
97	Fastening	2 days	Fri 3/12/21	Mon 3/15/21			100%
98	Lid	1 day	Mon 3/29/21	Mon 3/29/21			100%
99	Door slots (waterjet)	1 day	Tue 3/30/21	Tue 3/30/21			100%



ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	% Complete
100		Crank arm	1 day	Wed 3/31/21	Wed 3/31/21			100%
101		Hooks and hook panel	1 day	Tue 3/30/21	Tue 3/30/21			100%
102		**CNC/Mill machining**	**4 days**	**Wed 3/31/21**	**Sat 4/3/21**			**100%**
103		Door knob	1 day	Wed 3/31/21	Wed 3/31/21			100%
104		Coil insert	2 days	Thu 4/1/21	Fri 4/2/21			100%
105		Guide rails	1 day	Fri 4/2/21	Fri 4/2/21			100%
106		Knob	1 day	Sat 4/3/21	Sat 4/3/21			100%
107		Inspect and test components	1 day	Mon 4/5/21	Mon 4/5/21	102		100%
108		Assemble Round 1 verification	2 days	Tue 4/6/21	Wed 4/7/21	107		100%
109		VP round 1 inspections/basic tests	3 days	Thu 4/8/21	Mon 4/12/21	108		100%
110		Re-orders	5 days	Thu 4/8/21	Wed 4/14/21	108		100%
111		Re-machining components	1 wk	Thu 4/15/21	Fri 4/23/21	110		100%
112		VP round 2 inspections/basic tests	2 days	Mon 4/26/21	Tue 4/27/21	111		100%
113		Pad Time	4 days	Thu 4/22/21	Tue 4/27/21			100%
114		Verification Prototype Sign-Off	0 days	Tue 4/27/21	Tue 4/27/21		All	100%
115		**Micro-g NExT Milestone 3**	**7 days**	**Mon 4/12/21**	**Tue 4/20/21**			**100%**
116		3A: Proof of Concept Video	2 hrs	Thu 4/15/21	Thu 4/15/21		All	100%
117		3B: TEDP	1 wk	Mon 4/12/21	Tue 4/20/21		All,Heidi	100%
118		3C: Shipping Container Specs	2 hrs	Fri 4/16/21	Fri 4/16/21		All	100%
119		Milestone 3 Due	0 hrs	Tue 4/20/21	Tue 4/20/21	116,117,118		100%
120		**Verification Prototype Testing**	**30 days**	**Wed 4/14/21**	**Tue 5/25/21**			**100%**
121		Verify interface	1 day	Tue 4/27/21	Tue 4/27/21		Oscar	100%
122		Safety Inspection	2 days	Wed 4/28/21	Thu 4/29/21	114		100%
123		Test Plan Development	10 days	Wed 4/14/21	Tue 4/27/21			100%
124		Structural Testing	2 days	Fri 4/30/21	Mon 5/3/21	122		100%
125		Ease-of-Use Testing (terrestrial)	3 days	Tue 5/4/21	Thu 5/6/21	124		100%
126		Underwater Testing	3 days	Tue 5/4/21	Thu 5/6/21			100%
127		Modifications	1 wk	Thu 5/6/21	Fri 5/14/21		Kristin	100%
128		Rebuild and Test	1 wk	Mon 5/17/21	Mon 5/24/21	127	Kelsey	100%
129		VP Finalized	0 days	Tue 5/25/21	Tue 5/25/21		All	100%
130		Micro-g NExT Focus Session 5	1 hr	Wed 5/12/21	Wed 5/12/21		All	100%
131		May Monthly Status Report	2 hrs	Wed 5/26/21	Wed 5/26/21		Kristin	100%
132		**Documentation**	**21 days**	**Wed 4/28/21**	**Tue 5/25/21**			**75%**



ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	% Complete
133		Document correct operation	21 days	Wed 4/28/21	Tue 5/25/21		Oscar	75%
134		**Micro-g NExT Milestone 4**	**10 days**	**Wed 5/12/21**	**Tue 5/25/21**			**100%**
135		4A: Info for FedEx Label	0 days	Wed 5/12/21	Wed 5/12/21		Kristin	100%
136		4B: Ship Tools	0 days	Tue 5/25/21	Tue 5/25/21	135	All	100%
137		**Final Design Review**	**7 days**	**Mon 5/17/21**	**Tue 5/25/21**			**13%**
138		Update Sections	4 days	Mon 5/17/21	Thu 5/20/21		All	20%
139		Write conclusions and recommendations	1 day	Fri 5/21/21	Fri 5/21/21	138	Kristin	0%
140		Edit, Format, Check Citations	1 day	Mon 5/24/21	Mon 5/24/21	139	Kristin	0%
141		Submit FDR	0 days	Tue 5/25/21	Tue 5/25/21	140	All	0%
142		**Expo Presentation**	**11 days**	**Fri 5/21/21**	**Fri 6/4/21**			**95%**
143		Create Website	11 days	Fri 5/21/21	Thu 6/3/21		All	95%
144		Expo Website Finalized	0 days	Fri 6/4/21	Fri 6/4/21		All	0%
145		Micro-g NExT Unboxing Session	1 day	Wed 6/2/21	Wed 6/2/21		All	40%
146		**Micro-g NExT TRR Presentation**	**7 days**	**Tue 6/1/21**	**Thu 6/10/21**		**All**	**0%**
147		Prepare Presentation Materials	3 days	Tue 6/1/21	Thu 6/3/21			0%
148		TRR Review	1 day	Fri 6/4/21	Fri 6/4/21	147	Heidi,Noori	0%
149		Practice TRR Presentation	1 day	Wed 6/9/21	Wed 6/9/21	148		0%
150		TRR Presentation	0 days	Thu 6/10/21	Thu 6/10/21	149		0%
151		**Micro-g NExT Remote Testing Week**	**6 days**	**Tue 6/15/21**	**Tue 6/22/21**		**All**	**0%**
152		Test Date	1 day	Tue 6/15/21	Tue 6/15/21			0%
153		Document results	5 days	Wed 6/16/21	Tue 6/22/21			0%
154		**Micro-g NExT Final Report**	**28 days**	**Tue 6/1/21**	**Thu 7/8/21**			**0%**
155		Technical Report Draft	2 wks	Tue 6/1/21	Fri 6/18/21			0%
156		Incorprate Results from Test Week	1 wk	Mon 6/21/21	Tue 6/29/21			0%
157		Technical Report Review	5 days	Wed 6/30/21	Mon 7/5/21	156		0%
158		Outreach Report Draft	2 wks	Tue 6/1/21	Fri 6/18/21			0%
159		Outreach Report Review	5 days	Tue 6/15/21	Mon 6/21/21			0%
160		Turn in Reports	0 days	Thu 7/8/21	Thu 7/8/21			0%

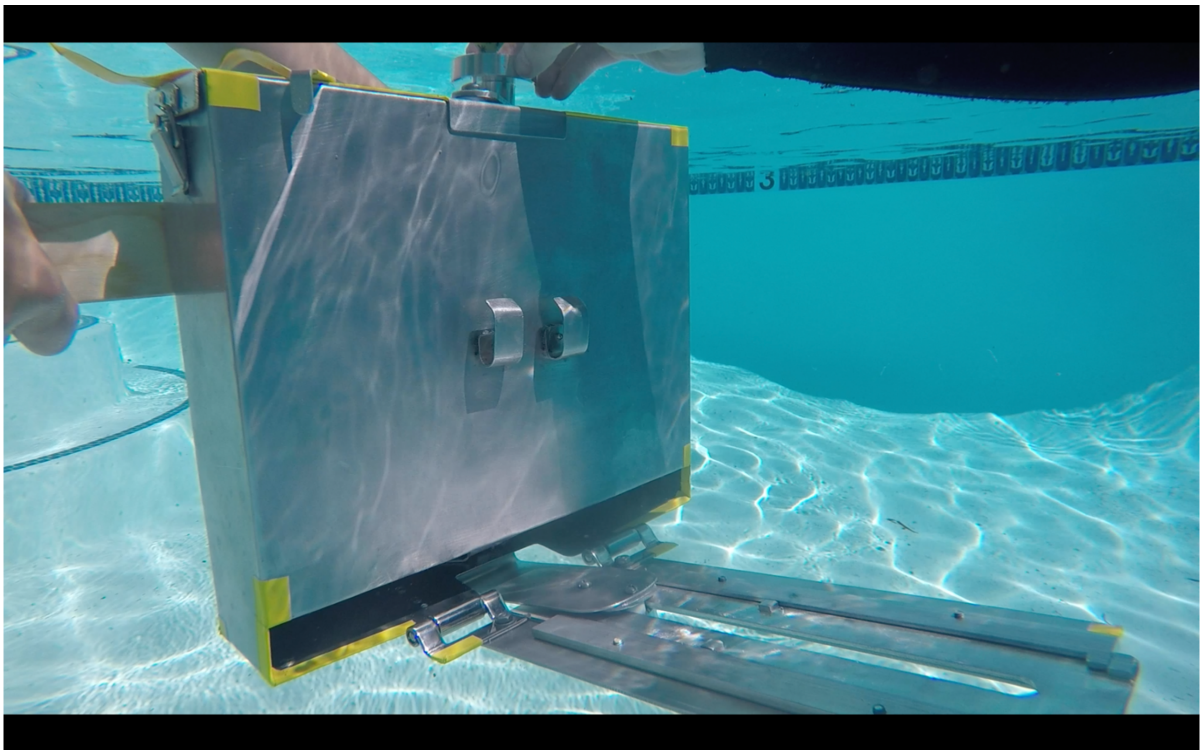


Appendix N: User Manual

Micro-g NExT One-Handed Operational Device (MOOD)

Neutral Buoyancy Lab Test Plan and Operations Manual

DRAFT



F26 Mustangs on the Moon

Kristin Kraybill-Voth, Kelsey Mickelson, Oscar Popravka

Updated 6/1/21

This test manual outlines the preparation and operation of the Micro-g NExT One-Handed Operational Device (MOOD) for testing in the Neutral Buoyancy Lab at Johnson Space Center. Please read the manual in its entirety before proceeding with any actions. The goal of this test is to qualify the functionality of MOOD through user feedback. Our project video provides additional visuals of the components and operation of the device: https://youtu.be/xz7fOiXEto0.

Safety Hazards

MOOD has two main safety hazards which may be encountered during typical use:

- **Sharp Edges** have been identified and labelled *yellow* to warn the user to avoid contact with those areas. The sharp edges could tear gloves or the suit or cause cuts/abrasions to bare skin during pre-flight handling.
- **Pinch Points** are associated with the operation of the door mechanism which could result in possible entrapment of fingers or loose equipment. The door is operated with manual power and its motion can be easily reversed to avoid entrapment. The areas of the door mechanism closest to the hinge point have also been labeled *yellow* to warn the user from placing hand or objects in these areas.
- **Snag Points** may occur at the hooks on the container or on the door's sliding hook panel. This could cause separation of equipment from the suit or potential tearing. These snag points are labelled *yellow* to notify the user of the hazard to be avoided.

These hazards with the labelling described above are shown in Figure 1.

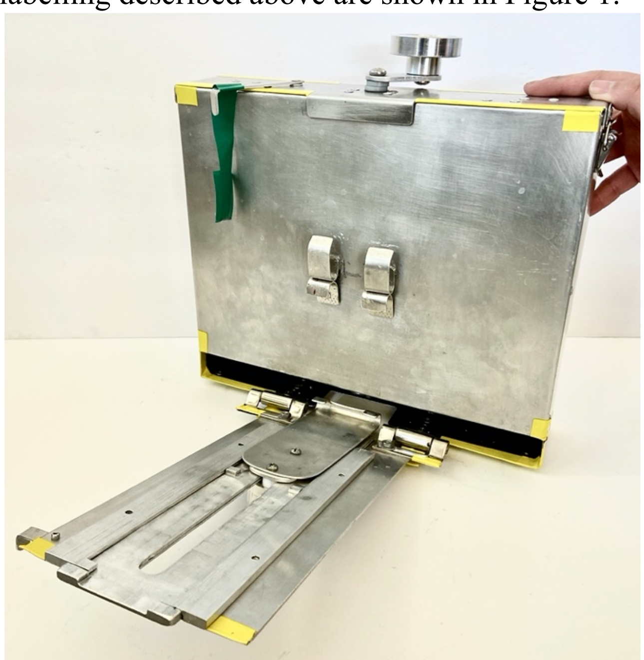


Figure 1. Possible hazards located on MOOD labelled with yellow electrical tape. Note these locations and avoid contact when possible.

Unboxing and Testing Equipment

- 1x pair EVA gloves
- 1x xEMU belt mock-up & swing arm
- 1x Device attachment interface
- 4x #10-24 bolts
- 1 x Communications system
- 5 x Lunar Surface Sample Bags
- 1 x MOOD Device
- 1 x #2 Phillips Screw Driver

Step 1: Unboxing and Assembly

The MOOD device is stored in a Pelican case. The case is closed via its latches as well as zip ties. Cut the zip ties, undo the latches, and open the top of the container. The MOOD device is packed such that minimal assembly is required. Figure 2 shows the packed configuration. Please refer to Figure 3 for a labelled view of MOOD.

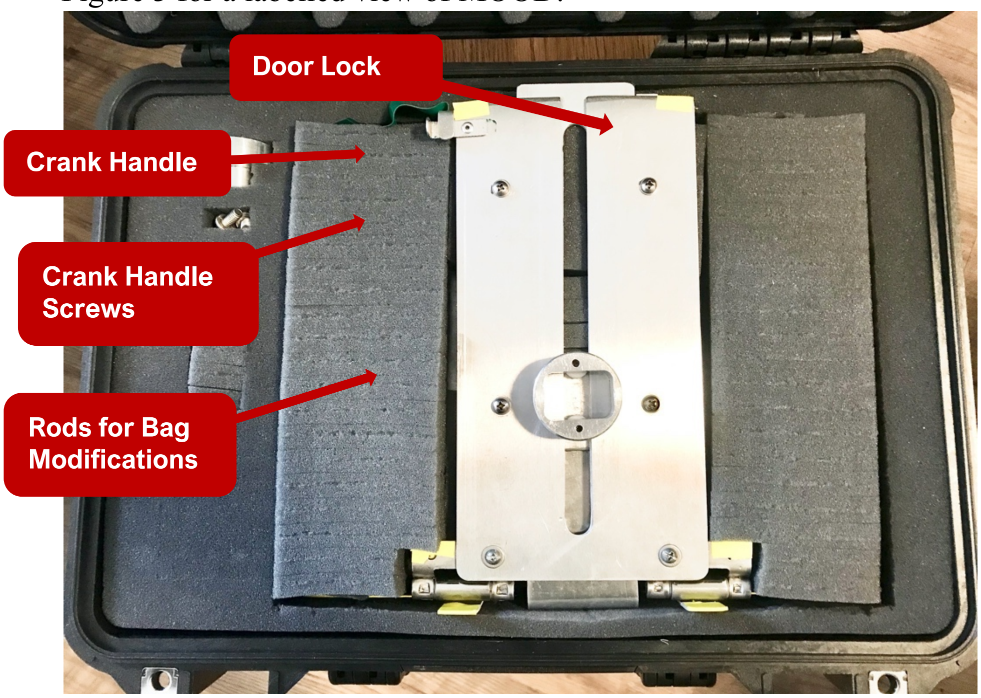


Figure 2. Interior Pelican case view with MOOD as shipped.

Packing List:

- 1x MOOD Device Main Assembly
- 1x Crank Handle
- 3x Stainless Steel ¼-20 bolts, ½" length
- 12x Stainless Steel Rods for bag modifications. 5 labeled with green tape, 7 unlabeled.
- Misc. foam pieces for packing

In order to prepare MOOD for operation:

1. Undo the door lock. Press the door inwards slightly and rotate door lock clockwise such that the two bent pieces are no longer interlocked.

2. Carefully rotate the door outward. The hook panel attached to the door may have shifted during transport causing it to catch on the container opening.
3. Remove all loose foam pieces. Set aside for future packing.
4. Lift the device out of the large compartment.
5. Undo the draw latches located on both sides of the device. Remove the lid by pulling it vertically out of the container. Remove foam pieces from the interior of the container.
6. With the lid removed, attach the crank handle. Remove the handle from the pelican case and one handle screw. Extras (1/4-20, ½” length) have been provided if needed. Pass the knob screw through the clearance hole on the crank arm. Insert the screw in the threaded hole on the underside of the crank handle. Use the #2 Philips screwdriver to tighten.

Step 2: Pre-Flight Inspection
First familiarize yourself with the MOOD device. Below, in Figure 3, MOOD is shown with labels identifying the main components. There are three main subassemblies referred to throughout the operations procedure: the coil assembly, the container, and the door assembly. The coil assembly is housed inside the container and is shown on its own in Figure 4.

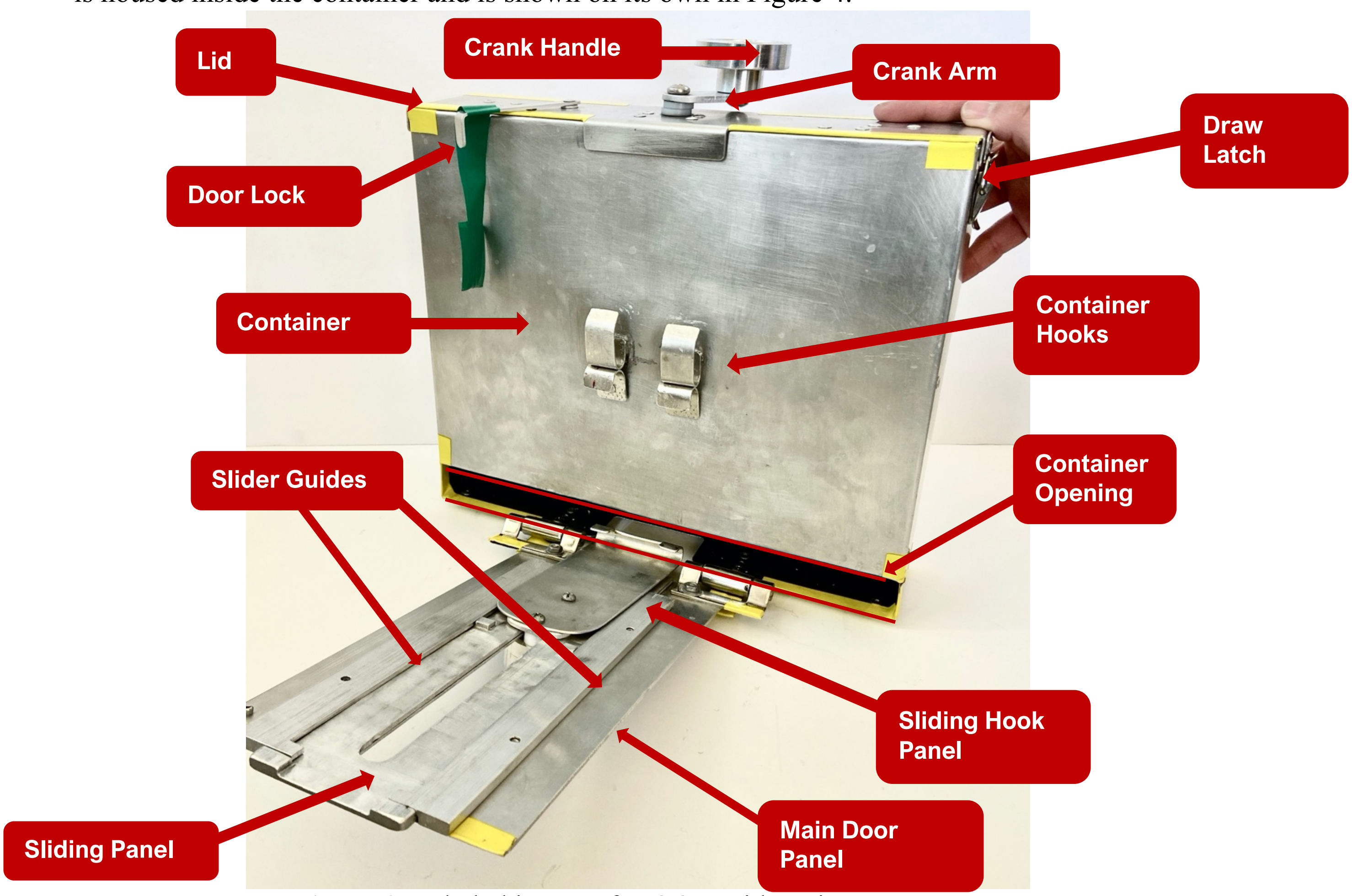


Figure 3. Labeled image of MOOD with main components.

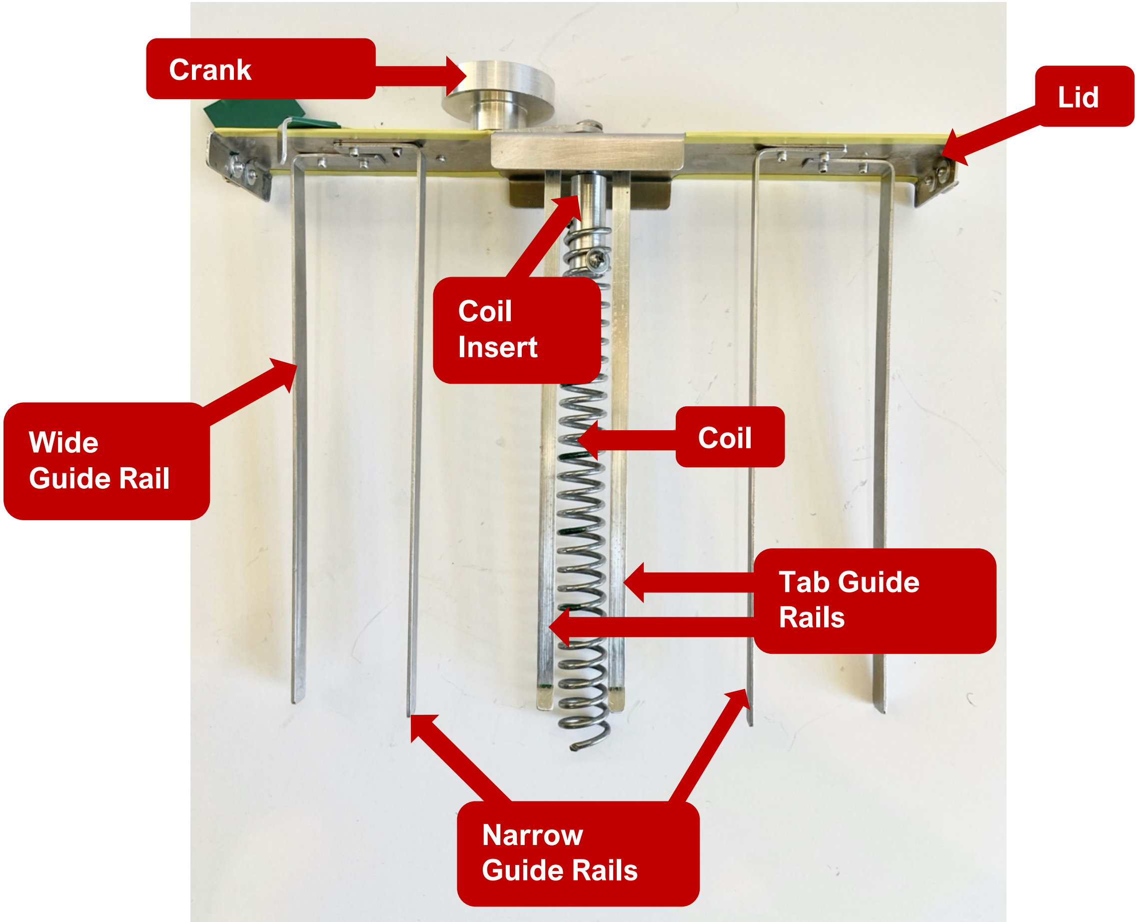


Figure 4. Coil assembly with components labeled.

With the device in front of you, identify the hazards discussed above. If any additional hazards are identified, mark them with yellow electrical tape.

Step 3: Sample Bag Modifications

The challenge-provided sample bag must be modified in order to be utilized with MOOD. The following steps must be repeated with each bag. Ten stainless steel rods (¼" in diameter and 2.3" long) and tape (such as electrical tape) are necessary for this modification. Five must be bare, and five must have green electrical tape around the circumference at two points.

1. One Teflon tab of the bag will be longer than the other. For the long tab, center the bare rod horizontally so there are equal amounts of rod overhanging each side of the tab.
2. Pull the Teflon tab over the rod, leaving 0.75" of tab length between the rod and the rim of the bag, as shown in Figure 5.

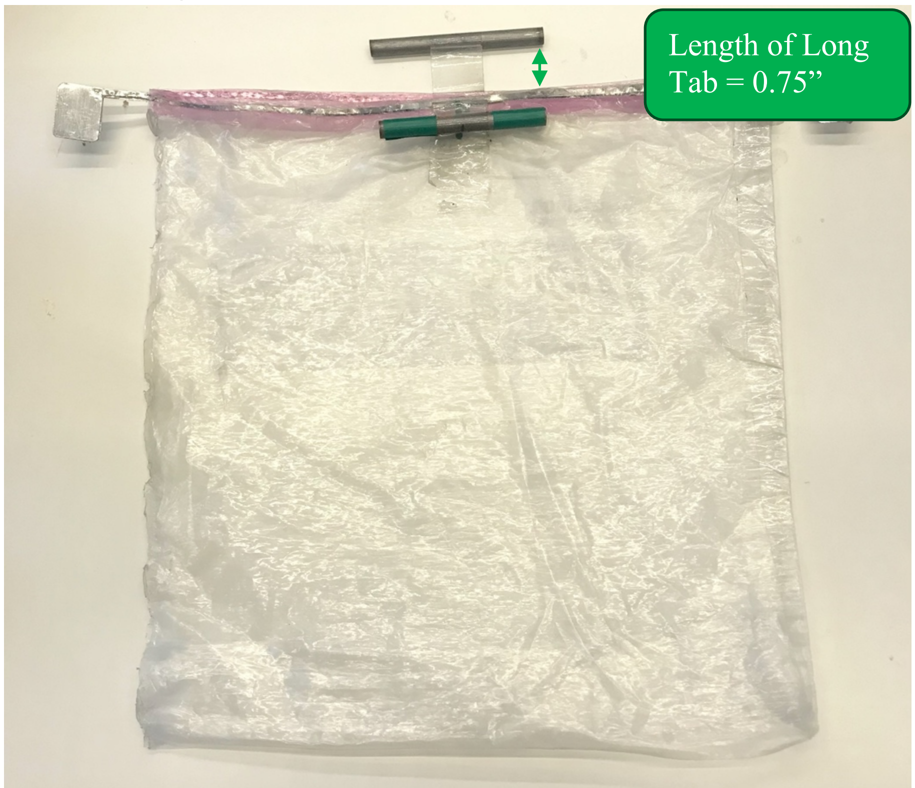


Figure 5. Rod placement for the long tab.

3. Secure the rod in the Teflon tab with an adhesive. We have used electrical tape, but if other methods are more appropriate for the Teflon tab they may be applied here.

Figure 6. Securing the Teflon tab and rod with adhesive.

4. Flip the bag over to create the short tab. Center the green rod horizontally so there are equal amounts of rod overhanging each side of the tab.

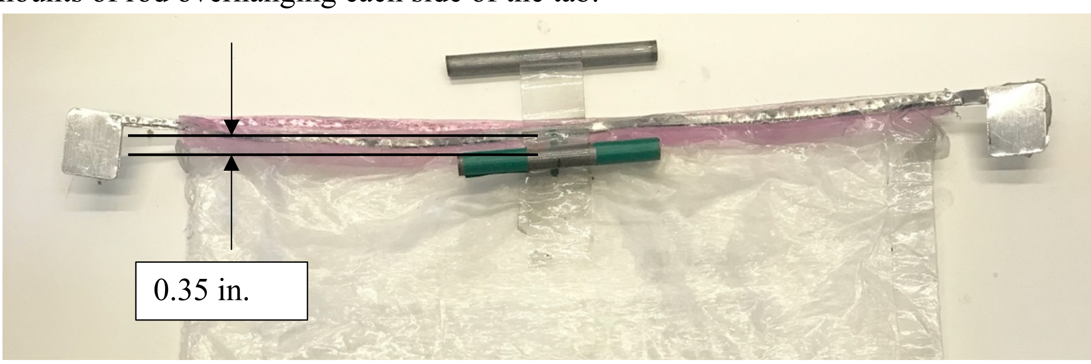


Figure 7. Placement of rod in Teflon tab for short tab.

5. Wrap the Teflon tab over the rod, leaving 0.3-0.35” of tab length between the rod and the rim of the bag. Trim excess tab.
6. Secure the rod in the Teflon tab with an adhesive as discussed with the long tab.
7. Alternatively, remove existing tab. Wrap electrical tape around the rod and affix the tape to the bag where the Teflon tab was formerly located, such that the electrical tape acts as the tab.
8. Ensure the bag rim is closed and flat.

Step 4: Pre-Flight Loading

1. Remove the lid from the top of the container by undoing the draw latches on the sides and lifting straight up.

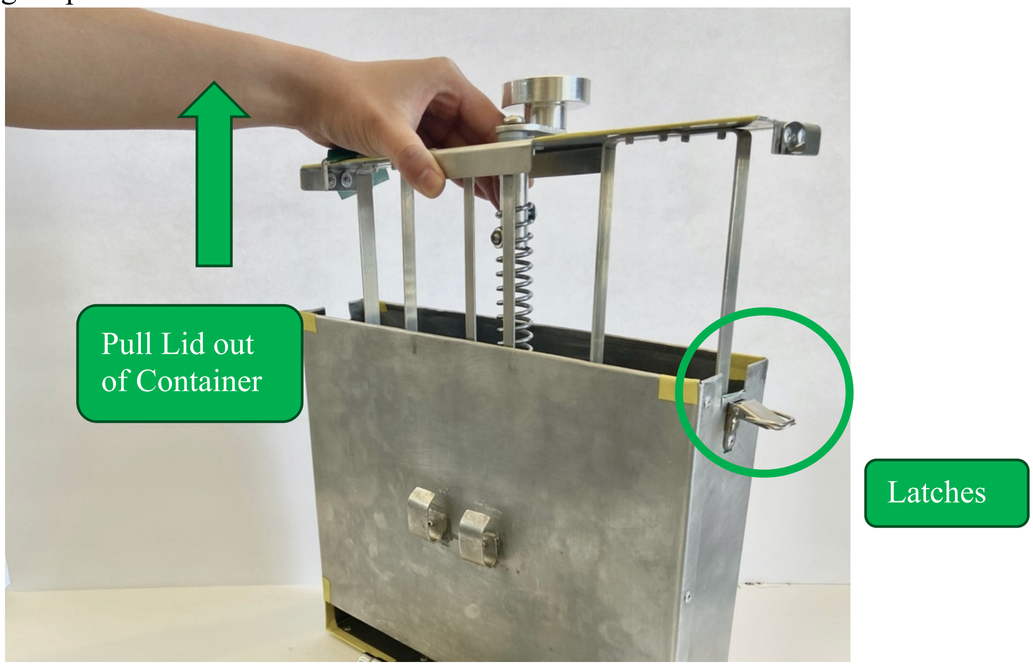


Figure 8. Lid removal.

2. Flatten the bag rim using a vice. Roll up five sample bags starting from the bottom, rolling inwards towards the longer Teflon tab. Roll the bags tightly. Both tabs should be outside of the rolled bag.

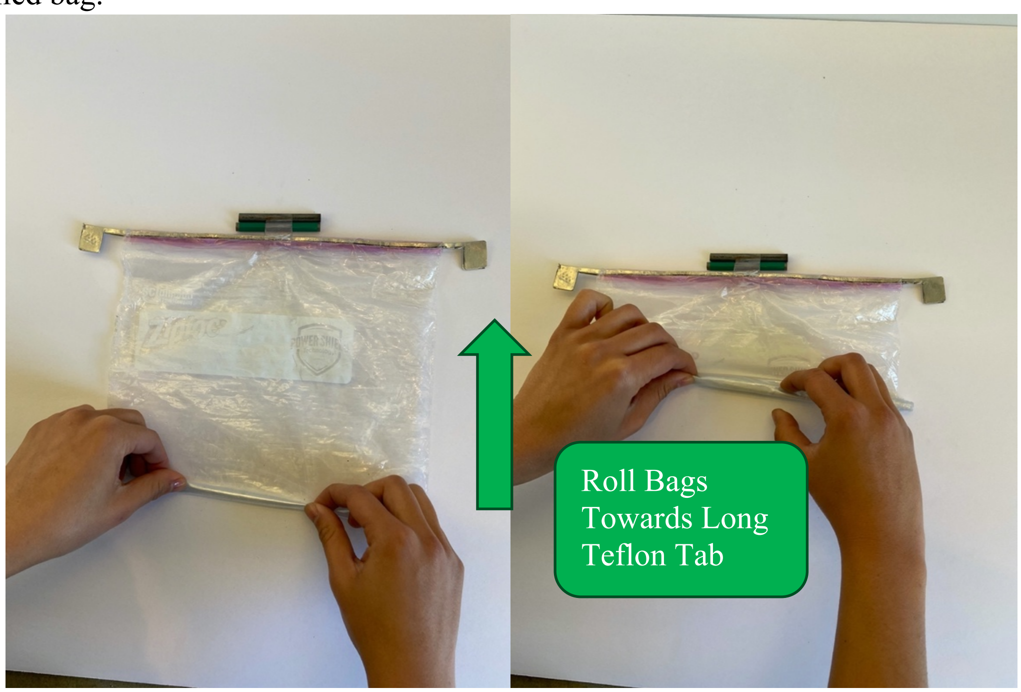


Figure 9. Bag being rolled inwards on the side with the longer Teflon tab.

3. If possible, submerge the bag underwater and squeeze out any air bubbles, and **proceed with loading underwater.**
4. Position the lid on a flat surface with the narrow guide rails and tab guide rails upwards. Slide the rolled bag between the coil and the narrow guide rails. Ensure the stainless-steel rods are on top the rod alignment guides, with the Teflon tab between the rails. The green rod should be above the bare rod. The tab guide rails have markings in green sharpie to indicate approximately where the green rods should fall.

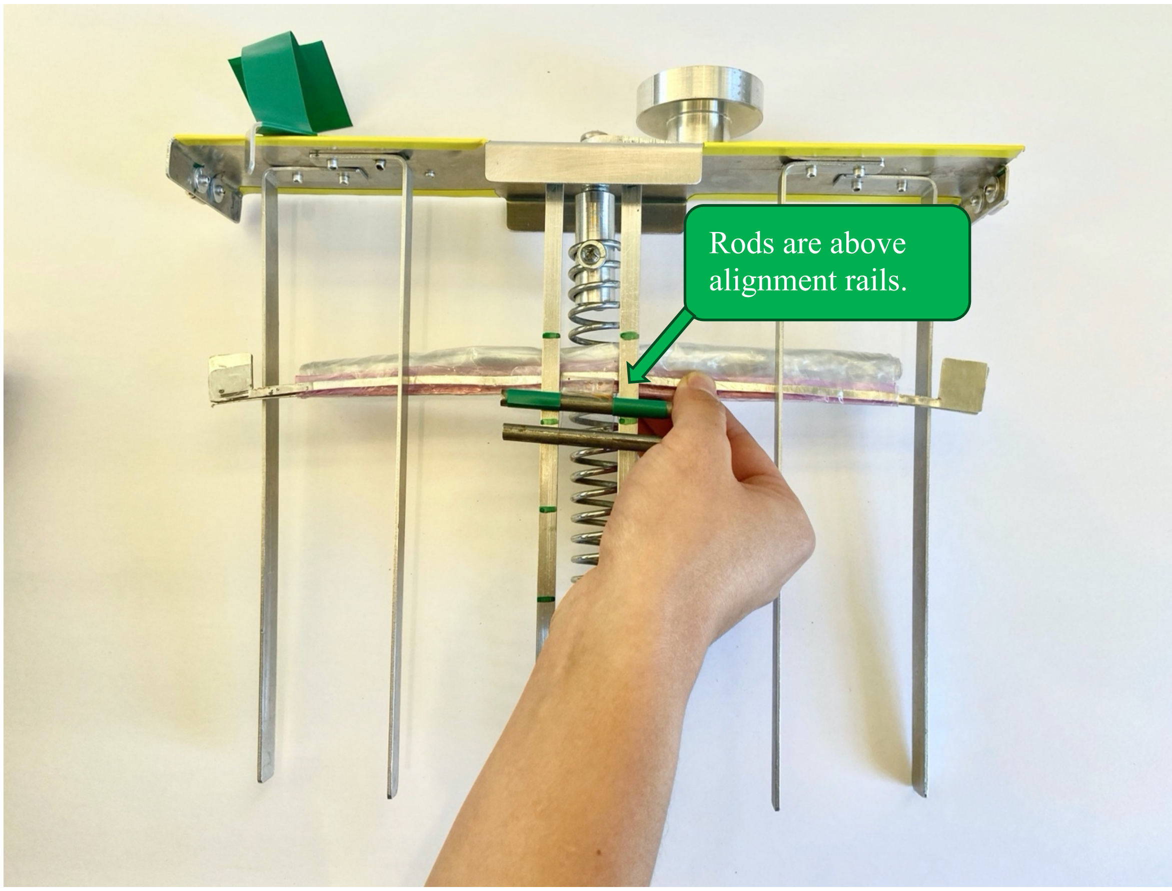


Figure 10. Bag placed between the coil and narrow guide rails during loading.

5. Rotate the rolled bag and push the bag material it into an upper coil slot. The opening of the bag should face the front of the lid as seen in Figure 11.
6. Ensure the aluminum flags are aligned on the exterior edge of the wide guide rails to constrain motion during dispensing process.

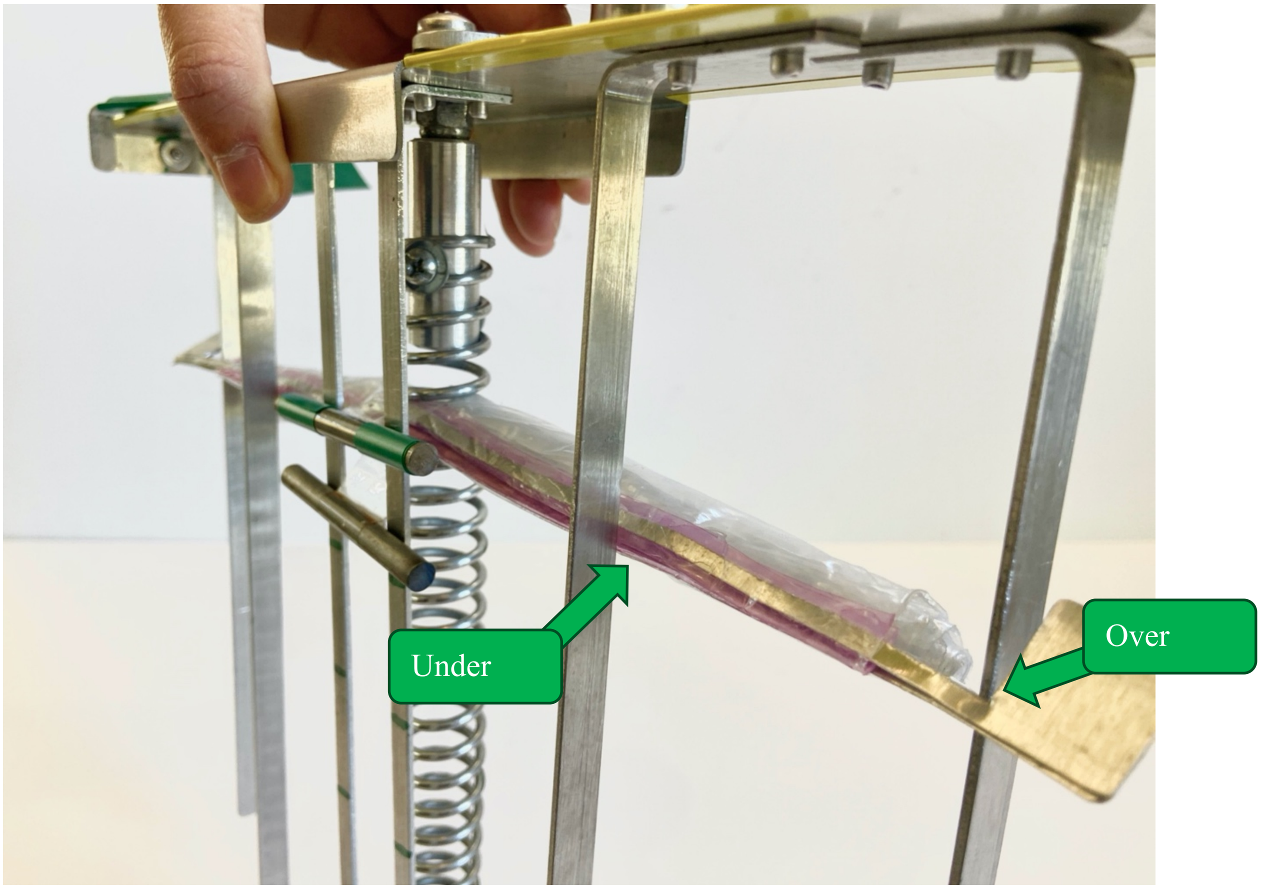


Figure 11. Bag inserted into a coil slot, with the bag's aluminum tabs and rim correctly placed within alignment walls.

7. Repeat with the additional four bags, evenly spacing them within the coil, approximately every three coil spaces.

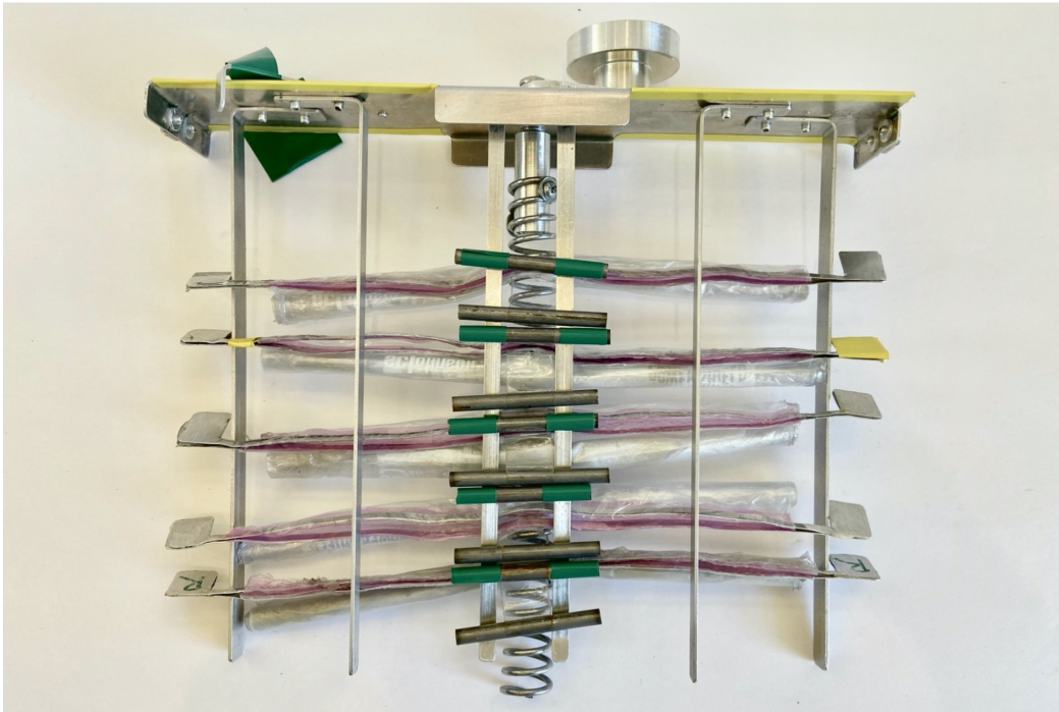


Figure 12. Fully loaded coil with five bags.

8. Secure the bag container to the mounting location via the 4-hole bolt pattern on the back of the container. Clearance holes allow for #10 bolts to pass through. Bolt heads should be inside of the container.

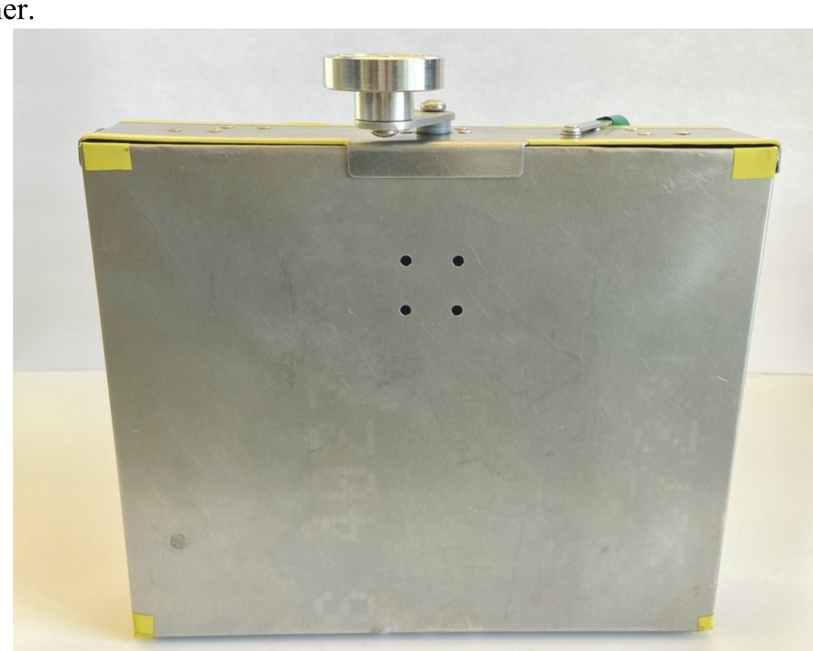


Figure 13. Four-hole bolt pattern (15/16” spacing) on back of bag container.

9. In order to replace the lid and coil mechanism in the container, certain alignment must be achieved with the coil. In the bottom of the container, there are three alignment guides perpendicular to the bottom surface, as seen in Figure 14.

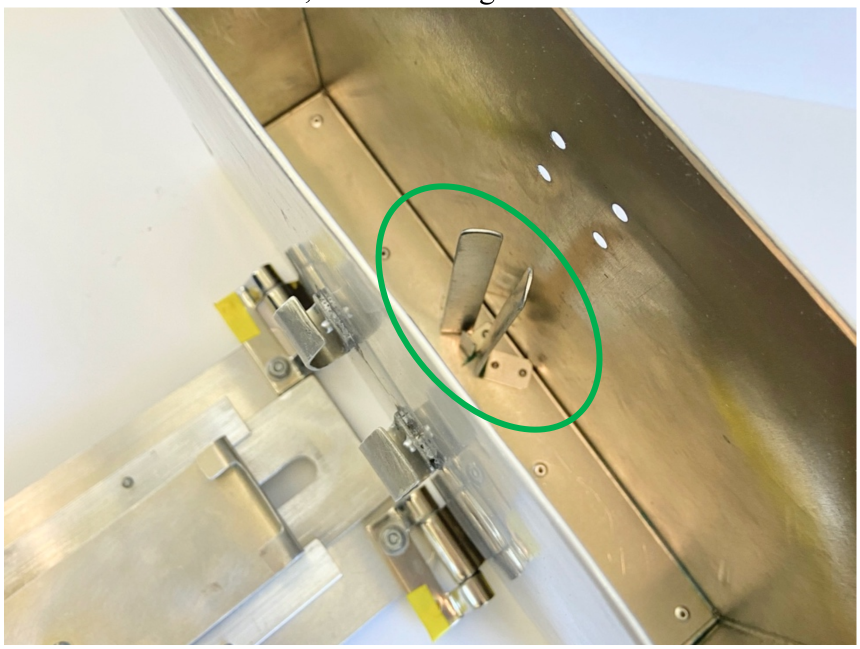


Figure 14. Coil alignment guides at the bottom of the bag container.

10. The coil must be placed as shown in the schematic below in Figure 15. The coil is represented in red. There are two angled alignment guides shown in blue. The coil must be in front of these guides and will be in physical contact with them. The coil must be placed over the center guide as shown in green. The proper placement can be seen in Figure 16.

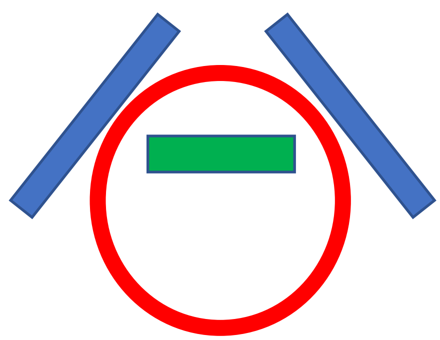


Figure 15. Coil arrangement schematic.

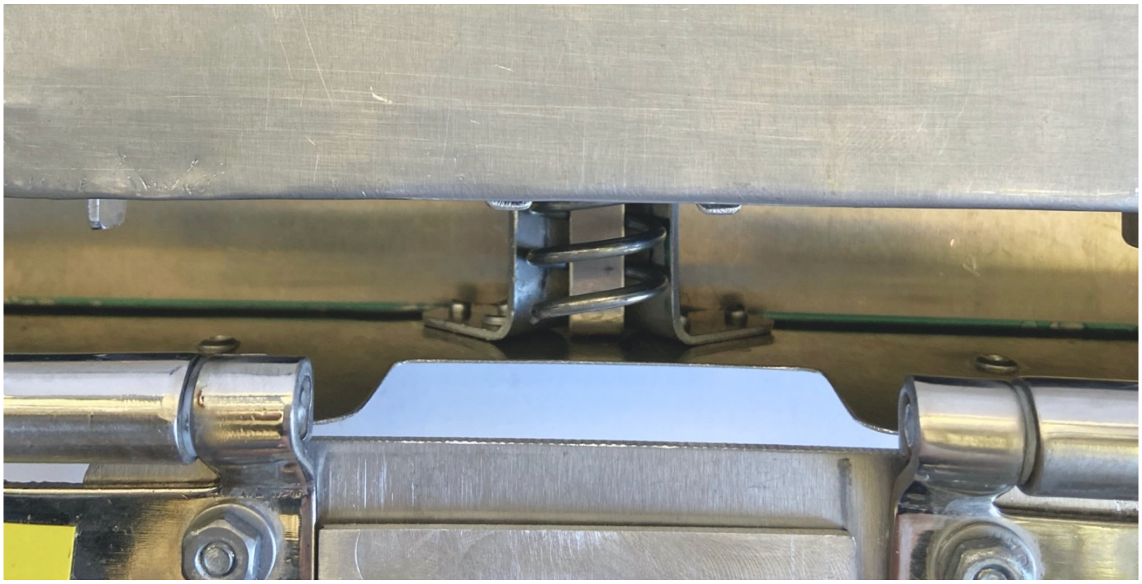


Figure 16. Correctly positioned coil: central alignment guide is inside of coil, while coil rests in front of "V" alignment guides.

11. Ensure the 90º tabs are on the outside of the bag container. Close the draw latches on the sides.

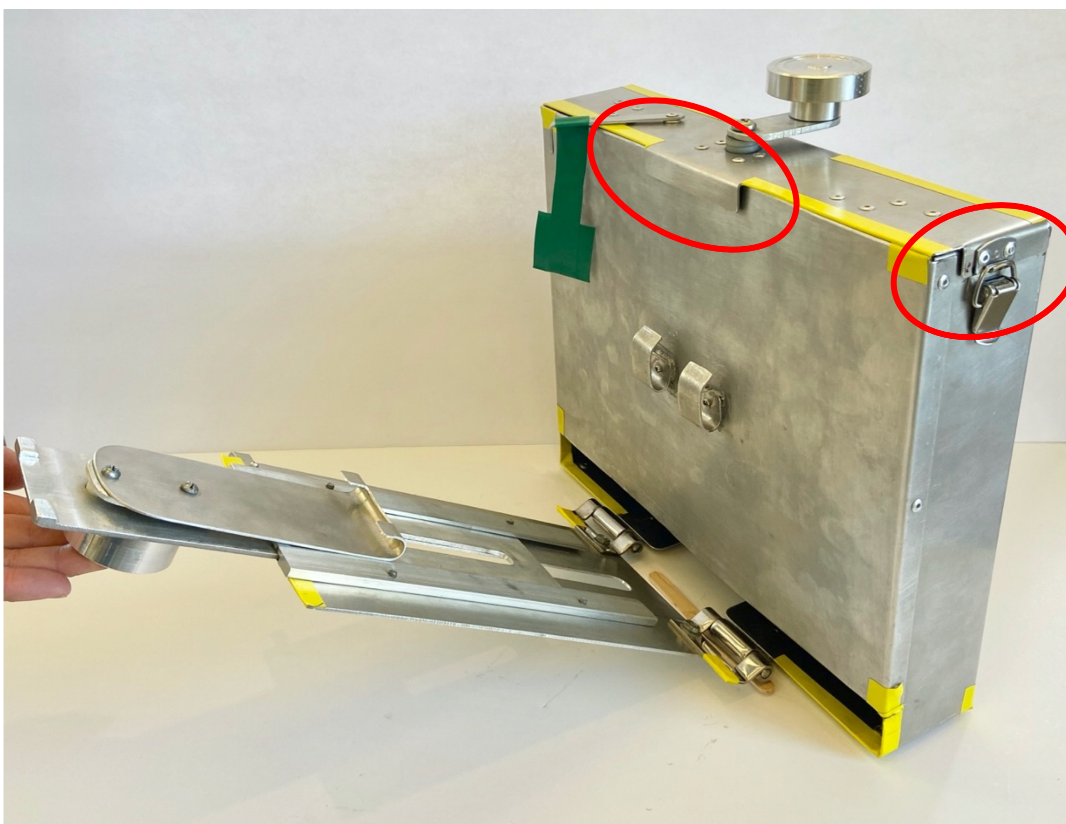


Figure 17. Correct lid alignment with tabs on outside of bag container.

12. Rotate the door shut with the door sliding knob at its lowest position near the bottom surface of the bag container.

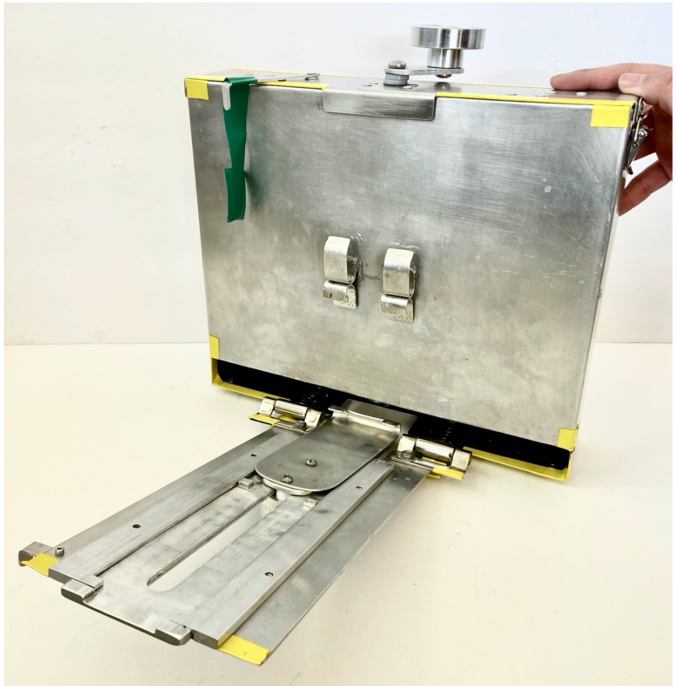


Figure 18. Door sliding knob at lowest position.

13. Grab the green tab and use it to rotate the door lock over the door to prevent outward rotation. The two sides must interlock.

Figure 19. MOOD with lid closed via draw latches and door lock engaged.

Step 5: Nominal Underwater Test Operations

Step 5a: Dispensing Procedure

14. Push in the door with one hand and use your free hand to grab the green tab on the door lock. Rotate the door lock clockwise until it rests against the container.

15. Grab the knob on the backside of the door panel and open the door to a 90-degree angle. Then slide the knob to its lowest position and ensure the hooks on the panel are past the notch in the bottom surface of the container. The door can rest in this position.

16. Rotate the top crank handle on the lid counterclockwise to rotate the coil. After approximately 3-5 turns, looking through the opening of the container you should see the rods appear.

17. Once the smaller rod with the green tape is visible, grab the doorknob and extend it away from the door at a 45-degree angle. This motion should hook the lower rod (the rod without green tape). Fully extend the door outwards and upwards.

18. The smaller tab with green tape should be hanging loosely on the other side of the bag. Rotate the door until it's vertical. Lower the doorknob until the smaller tab's rod is hooked in the container hooks.

19. Once both rods on the tabs are hooked, open the door completely to begin sampling.

Step 5b: Sampling Procedure

20. Let go of the device, the door should be resting on the stops while the bag is open and resting on the door. Place the desired sample into the open bag.

21. Once the sample is collected in the bag, rotate the door panel inwards to release the tension in the bag rods and remove the bag containing the sample by lifting the bag upward and out of the MOOD.

22. Engage the door lock to prevent door rotation.

23. Fold the aluminum ring downwards to close the sample bag and fold both side tabs inwards to ensure it is properly sealed. Stow the filled sample bag into the designated compartment which will keep the rest of the samples safe until the return to Earth.

24. Repeat process until all bags are used or until sampling procedure is completed.

Step 6: Contingency Test Operations

Below is a list of possible problematic events that might take place during testing along with the corresponding action that should be taken if the event occurs.

Table 1. Table of Mitigative Actions for Problematic Events.

Event	Action
The bags get tangles together in the container or coil.	1. Unlock latches on the side of the lid 2. Remove the lid to inspect situation of bags 3. If possible, take the bags and roll them in the correct configuration 4. Reinsert the bags into the coil 5. Lock lid back in place
Aluminum rods on tabs are not grabbed by hooks.	1. Try to lean or tilt the device towards you, so the rods fall out and away from the container 2. If possible, move the container and the door knob until you are able to hook on to the rod 3. If the previous method does not work, giggle the doorknob until the hook is captured
Smaller tab rod is stuck inside the bag.	1. Lower the doorknob below the emergency hooks 2. Move the knob upwards to hook the emergency hooks onto the smaller tab rod 3. Once hooked, pull the door outwards and slightly downwards to try to have the hooks roll the rod out of the bag

Step 7: Test Results Evaluation

Our design will be evaluated on its ease of use with limited dexterity in a spacesuit. In the NBL, astronaut divers will test the accuracy of our device by dispensing 5 lunar geological sample bags. The following table will be used to capture data during the test:

Table 2. Sample Data Collection Table.

Run	Dispense	First Hook	Second Hook	Notes
1	Pass or Fail	Pass or Fail	Pass or Fail	Observations
2				
3				
4				
5				
Total				

The following questions will be asked after each bag dispensing cycle to evaluate ease of use:

1. On a scale of 1 to 5 with 5 being most positive, how would you rate the ease of using the crank knob on the lid to dispense the bags?
2. On a scale of 1 to 5 with 5 being the most positive, how would you rate the ability to pull the bag out of the container?
    a. Did lack of visibility of the rods impact your ability to hook the first rod and pull the bag out of the container?
3. On a scale of 1 to 5 with 5 being most positive, how would you rate ease-of-use of the door knob to operate the door and slider?
4. On a scale of 1 to 5 with 5 being the most positive, how would you rate the ease of placing the second rod in the container-side hooks?
5. If applicable, on a scale of 1 to 5, how useful were the emergency hooks to help free the rod from the bag opening?

The following questions will be asked after the completion of all five sample-bag dispensing cycles:

1. Did the size of the device impair your mobility/motion?
2. On a scale of 1 to 5, how would you rate the ability to use the device with just one hand?
3. Is there any additional feedback or observation you would like to provide?

Step 8: Re-Packing

1. Ensure the MOOD device is fully dry.
2. Undo the draw latches located on both sides of the device. Remove the lid by pulling it vertically out of the container.
3. Remove the crank handle. Use a #2 Philips screwdriver to loosen the 1/4-20 bolt on the underside of the crank handle and crank arm. Store the handle in the pelican case and place the screws in the small compartment.
4. Place foam pieces in the interior of the container. Several pieces were used to pad the alignment rods to prevent excessive motion. Re-place the lid carefully and close the draw latches.
5. Place the container back in the large compartment in the pelican case. The door should still be able to rotate freely.
6. Pack a piece of foam underneath the upward facing hooks on the container. Place foam underneath the door, and rotate it shut. Place foam on either side of the door.
7. Rotate the door lock closed by interlocking the two L-shaped pieces. The door may need to be pressed inward slightly to achieve this.
8. Carefully rotate the door outward. The hook panel attached to the door may have shifted during transport causing it to catch on the container opening.
9. Close the lid of the pelican case and ensure it is latched. Use zip-ties to secure.
10. Please refer to the packing list in Step 1 to ensure all components have been included, aside from the bag modification rods. These do not need to be returned.

APPENDIX O: TEST PROCEDURES

Underwater Test Procedure

Test Name: Underwater Ease-Of-Use Test
Purpose: The purpose of this test is to determine the efficiency and functionality of our MOOD device underwater. We will attempt to replicate the NBL testing environment as close as possible to perform realistic tests.
Scope: The primary functions to be tested are bag dispensing (coil and crank) and bag opening (slider door, hooks, bag tab modifications). We also want to evaluate the difficulties of performing the dispensing procedure underwater and observe any characteristics or faults that arise due to the underwater environment.
Equipment: M.O.O.D., glove mock-up, device mounting set-up, sample bags, 2 lb. sample.
Hazards: Pinch points, sharp edges, drowning hazard.
PPE Requirements: Mask and tuba.
Facility: Community pool
Procedure:

1. Load bags into coil
2. Attach lid onto container
3. Attach container to modified belt
4. Give tester mask and tuba and safely position them underwater
5. Execute dispensing operation steps
6. Count bags dispensed
7. Collect qualitative feedback from user
8. Repeat with all available testers

Results: Pass Criteria, Fail Criteria, Number of samples to test

- **Pass criteria**: All 5 bags dispensed, ease-of-use rating above 3 out of 5
- **Fail criteria**: Bags become jammed, bags do not dispense, mechanisms jammed
- **Number of samples**: 5 bags

Test Date(s): 05/08/21 through 05/15/21

Test Results: Qualitative feedback, photographic and video documentation

Performed By: All team members

Test Procedure: Safety and Mechanical Inspections

Test Name: Safety and Mechanical Inspections

Purpose: This test will identify potential safety hazards and ensure the device meets the NASA standards set forth in the challenge descriptions.

Scope: Examine and measure the physical parameters (size, weight) and check for identified hazards (sharp edges, pinch points)

Equipment: Scale, measuring tape, ruler, calipers

Hazards: Cuts or pinched fingers due to sharp edges/pinch points

Potential Safety Issue	Response
Sharp edges	If a sharp edge causes a cut, evaluate whether the cut is deep and could require stitches. Administer first aid as necessary.
Pinch points	If a hand or finger is caught in a pinch point, immediately cease motion of the device and carefully extract the hand/finger. Identify any cuts and bruising. Apply first aid as needed.

PPE Requirements: Safety glasses, gloves

Facility: Well-lit table surface in Mustang 60 or Hangar

Procedure:

1. Gather the appropriate equipment and the assembled device.
2. Test the device overall weight. Zero the scale and place the device on top. Record the weight.
3. Measure the weights of the subsystems to identify where the majority of the weight is held. Separate the subsystems (container, lid/coil, door) and record individual weights.
4. Measure the exterior dimensions of the overall system. Place the container on a flat surface. Use the rulers or measuring tape to measure the exterior dimensions. Record these dimensions and compare them to the NASA criteria.
5. Use calipers to check the four-hole bolt pattern.
6. Measure the thickness of hemmed sheet metal edges. Use calipers to identify fillet sizes. Compare to NASA standards.
7. Run bare hands carefully over all exposed edges and corners of the device. Note the locations and nature of sharp edges to either be dressed or labelled as a hazard.
8. Take a piece of fabric and push over sharp edges to determine if edges would cause tearing.
9. Ensure notes/pictures have been taken. Record the results in the table.
10. Return all equipment.

Results: Pass Criteria, Fail Criteria, Number of samples to test

- Pass criteria:
  - Device weight below 3 lbs
  - Exterior dimensions within 12”x12”x5” volume
  - 4-hole bolt pattern matches specifications
  - Radii comply to NASA standard radii within 10%
  - Fewer than 5 sharp edges identified with plans to eliminate
- Fail criteria:
  - Exceeds 3 lb weight
  - Any dimension beyond the given volume
  - Bolt pattern does not match
  - More than 5 sharp edges identified

Test Date(s): 4/28/21 and 4/29/21

Test Results: Measurements, identified sharp edges/pinch points

Test	Result	Meet Criteria?	Notes
Weight	2 lb. 14.3 oz.	Yes	
Exterior Dimensions	11.75”x12”x4.25”	Yes	
4-hole bolt pattern	15/16” square	Yes	
Radius check	Check	Yes	Filed down additional points
Sharp edges	Check	Yes	Filed down where possible and added yellow tape for hazard warning

Performed By: Kristin Kraybill-Voth, Oscar Popravka, Kelsey Mickelson